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Modeling ordnance movements into the Asian Pacific Theater

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MONTEREY, CALIFORNIA

THESIS

MODELING ORDNANCE MOVEMENTS INTO THE ASIAN PACIFIC THEATER

by

Cielo I. Almanza

March 2009

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13. ABSTRACT (maximum 200 words)

This thesis explores the capabilities of ordnance movements into the Asian Pacific Theater. Through simulation, logistics modeling, and data analysis, this thesis identifies critical factors and capabilities that are important to the effective movement of ordnance by combat logistics ships through Guam during a military contingency. The experimental design incorporates the effects of competing requirements on the ordnance resupply process in Guam. The objective is to facilitate an evaluation of systems, identify possible improvements to fully exploit capabilities, and gain insights into the process methodology. Results indicate that the inclusion of competing requirements to the system degrades both Auxiliary Dry Cargo/Ammunition Ship (T-AKE) service level and the overall throughput of the system by nearly 25%. Analysis of critical factors contributing to this degradation indicates that the T-AKE arrival cycle is the largest contributing factor to the system's effectiveness. The results also indicate that competition is a contributor to the effects on the system, but is never the most influential aspect, and the decision of where to process ordnance is significant for the best-performing scenarios in the experiments. Lastly, the analysis clearly shows that improving the system's performance is not dependent on the distance of ordnance storage facilities from the wharf.

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MODELING ORDNANCE MOVEMENTS INTO THE ASIAN PACIFIC THEATER

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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ABSTRACT

This thesis explores the capabilities of ordnance movements into the Asian Pacific Theater. Through simulation, logistics modeling, and data analysis, this thesis identifies critical factors and capabilities that are important to the effective movement of ordnance by combat logistics ships through Guam during a military contingency. The experimental design incorporates the effects of competing requirements on the ordnance resupply process in Guam. The objective is to facilitate an evaluation of systems, identify possible improvements to fully exploit capabilities, and gain insights into the process methodology. Results indicate that the inclusion of competing requirements to the system degrades both Auxiliary Dry Cargo/Ammunition Ship (T-AKE) service level and the overall throughput of the system by nearly 25%. Analysis of critical factors contributing to this degradation indicates that the T-AKE arrival cycle is the largest contributing factor to the system's effectiveness. The results also indicate that competition is a contributor to the effects on the system, but is never the most influential aspect, and the decision of where to process ordnance is significant for the best-performing scenarios in the experiments. Lastly, the analysis clearly shows that improving the system's performance is not dependent on the distance of ordnance storage facilities from the wharf.

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THESIS DISCLAIMER

The reader is cautioned that the computer programs utilized in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

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LIST OF KEY WORDS, SYMBOLS, ACRONYMS, AND ABBREVIATIONS

(a_Arrival_Time_to_System)	Attribute for Entity Arrival Time to System
(a_Num_Containers)	Attribute for Number of Containers per Container Ships
(a_Pallets_Needed)	Attribute for Pallets Needed by T-AKE
(a_Ship_Type)	Attribute for Determining Ship Type
AAFB	Andersen Air Force Base
AF	Air Force
AO	Area of Operation
AOE-1	Fast Combat Support Ship, USS SACRAMENTO
AOE-6	Fast Combat Support Ship, USS SUPPLY
CCF	Container Capable Forklift
CCT	Container Capable Truck
CLF	Combat Logistics Force
CNA	Center for Naval Analyses
CNO	Chief of Naval Operations
COMNAVMARIANAS	Commander, U.S. Naval Forces Marianas
COMPACFLT	Commander, U.S. Pacific Fleet
CONOPS	Concept of Operations
CONUS	Continental United States
CRM	Center for Naval Analyses Research Memorandum
CS	Competing Ship
CVBG	Carrier Battle Group
Det	Detachment
DoD	Department of Defense
DOE	Design of Experiments
DZSP 21	Day and Zimmerman Services Inc., SKE Support Services Inc., and Parsons Infrastructure and Technology Group Inc.
ESQD	Explosives Safety Quantity Distance

GUI	Graphical User Interface
MEB	Marine Expeditionary Brigade
MHE	Material Handling Equipment
MILCON	Military Construction
MOE	Measure of Effectiveness
MPF	Maritime Prepositioning Force
MSDDC	Military Surface Deployment and Distribution Command
NAVBASE GUAM	Naval Base, Guam
NAVFACMARIANAS	Naval Facilities Engineering Command, Marianas
NAVSEA	Naval Sea Systems Command
NEW	Net Explosive Weight
NMC	Naval Munitions Command
NOLH	Nearly Orthogonal Latin Hypercube
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
OCS	Ordnance Container Ship
OLH	Orthogonal Latin Hypercube
OPLAN	Operational Plan
OPNAV N42	Director of the Strategic Mobility and Combat Logistics Division for the Chief of Naval Operations
PTT	Pallet Transport Truck
PWRMS	Prepositioned War Reserve Material Stock
SEED	Simulation Experiments and Efficient Designs
SL	Service Level
T-AE	Auxiliary Ammunition Ship
T-AFS	Auxiliary Combat Stores Ships
T-AO	Auxiliary Fleet Replenishment Oiler
T-AKE	Auxiliary Dry Cargo/Ammunition Ship
TEU	Twenty-Foot Equivalent Unit
TFIN	Simulation Finish Time

TNOW	Current Simulation Time
TRIA	Triangular Distribution
UNIF	Uniform Distribution
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
(v_Cont_per_OCS)	Variable for Containers per Container Ship
(v_CS_Arr_Time)	Variable for Competing Ship Arrival Time
(v_Initial_Inventory)	Variable for Initial Pallet Inventory
(v_OCS_Arr_Cycle)	Variable for Container Ship Arrival Cycle
(v_percent_Navy_Cont)	Variable for Percent of Containers, Navy
(v_percent_unstuffed_pier)	Variable for Percent of Containers Unstuffed Pierside
(v_TAKE_Arr_Cycle)	Variable for T-AKE Arrival Cycle
(v_Univ_Stream)	Variable for Setting Random Seed to a Universal Stream

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EXECUTIVE SUMMARY

As military campaigns evolve, there are a limited number of constants that hold true. One of these constants is the importance of sustainment and logistics capabilities. During a military crisis in which direct engagement is required, the ability to put ordnance on a target is vital to the concept of power projection. The underlying ability to sustain these operations is a logistics problem, which includes the continuous flow of commodities, such as ordnance, to the area of operation (AO). This logistics problem is equally important as the tactical problem, but often not as explored as the tactical application of targeting the ordnance. The responsibility then falls on the military logistician to study and explore the current and future possibilities of sustaining military actions.

Consider if there were a modeling tool that exercised the possible options when such an event arises. Then, the decision maker has a tool capable of guiding his or her decision, with respect to resource allocation, in order to effectively move ordnance through ports into an AO. The question then becomes how to provide our Auxiliary Dry Cargo/Ammunition Ships (T-AKEs) with the resources required to efficiently service our combatant ships. The forward-most port at which resources are received from the Continental United States (CONUS) and then readied for transfer becomes a key part of the answer to this question. This thesis studies this link—the logistic capabilities of moving ordnance into the Asian Pacific Theater—and provides a modeling tool to assist decision makers involved in ordnance operations.

The Asian Pacific Theater is a vast area and presents many logistics challenges. Moving ordnance into this area depends on three major evolutions. The first of these evolutions is the movement of ordnance from CONUS to a forward logistics base. This movement is done by large container ships originating from a handful of possible sources. Figure 1 illustrates the general flow of ordnance into the Asian Pacific Theater via Guam and displays how the movement of ordnance into the Asian Pacific is funneled into and through a single point of entry into the AO.

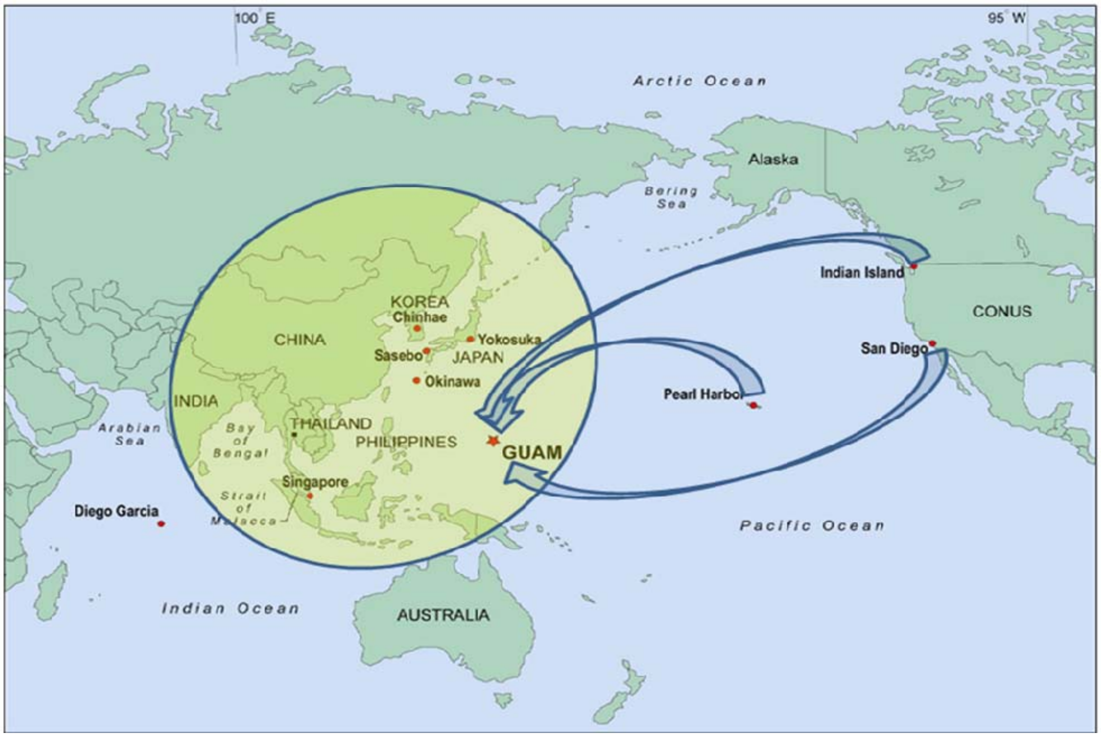

Figure 1. AO and Flow Paths of Inbound Ordnance.
(After: Helber, Hastert & Fee, 2003).

The second evolution is the processing of the containerized ordnance into palletized ordnance at the forward logistics base. These ordnance operations serve to process the ordnance for delivery to combatants. The ordnance operations for the AO of concern here are conducted on Guam. Guam's location is significant, as it is the western-most U.S. territory with the physical facilities capable of offloading, storing, and loading large amounts of ordnance. If Guam is eliminated as an ordnance operation resource, the Navy's next western-most capable facilities are in Hawaii, which results in a 3,320-nautical-mile difference in forward presence. Figure 2 provides an aerial view of the thesis study area and locations of interest for ordnance operations.

Figure 2. Map of Orote Peninsula Area, Guam (From: Goode & Smith, 2007).

The third evolution is the delivery of break-bulk ordnance to combatants at the forward edge of the battle. This task is carried out by Combat Logistics Force (CLF) ships. The specific CLF ship used in this thesis is the United States Navy's newest class of underway replenishment ships, the Auxiliary Dry Cargo/Ammunition Ship, Lewis and Clark Class (T-AKE). The T-AKE is designed to deliver ammunition, stores, and fuel to carrier and expeditionary strike groups. These new ships keep combatant ships at sea, on station, and combat-ready in any scenario.

The scenario established in this thesis is that the United States has become involved in a major military contingency in Asia and that T-AKEs are supporting the sea-based operation of a Maritime Prepositioned Force (MPF) squadron and its Marine Expeditionary Brigade (MEB) ashore. During such a contingency, the flow of supplies through Guam to forces at sea, or forces supported from the sea, is of critical importance. In order for T-AKEs to support only the sea-based operation of an MPF squadron and its MEB ashore, earlier studies have estimated how often they might have to go to port for resupply. In the case of a major military contingency, T-AKEs would also be supporting Carrier Strike Groups and other naval units. This translates to increased traffic intensity seen by the resupply port supporting the T-AKEs.

Given the scenario, a systems analysis of the major forward ordnance supply node of Asian Pacific Theater operations is conducted in an effort to answer these questions:

- How will introducing the competing requirements affect the predicted capabilities of the ordnance operations in Guam?
- What are the critical factors in the ordnance operations process?

Specifically, how do the competing requirements on the ordnance resupply process in Guam relate to other Department of Defense (DoD) needs to utilize the ordnance wharf, as well as their increase in ordnance requirements?

To answer these questions, the system is modeled using the discrete-event simulation package from Rockwell Software, Arena version 10.00. The focal point of the model structure is on the ordnance operations (specifically at the ordnance pier, Kilo Wharf) on Orote Peninsula, Guam. The available resources are varied within the simulation to account for differences in processing performance characteristics and operations. The Arena modeling environment is a powerful modeling tool that enables the creation and running of experiments on models of systems. An Arena simulation has a framework that consists of an entity-based simulation that can be data farmed within a design of experiments (DOE) environment. This allows for the simultaneous examination of multiple factors and explores the high-dimensional relationships of these factors. Through the use of an interchangeable, component-based architecture, the simulation provides the user with extensive capabilities to modify entities, configurations, simulation parameters, and select data output collected. Arena, using a low-resolution approach, runs fast and is easy to set up, which is advantageous in performing many analytical runs for comparison and exploration of the landscape of possible outcomes.

Use of the DOE approach to support the analysis of forward logistic capabilities provides data upon which quantitative analysis of the model is conducted, specifically looking at the effects of multidimensional, variable changes in an effort to estimate the effect on the frequency with which the T-AKEs could reload in Guam and the overall throughput of ordnance in the system.

The experimental design includes five scenario sets: two of which are baselines, while three are built with the DOE approach. The simulation model built in Arena contains the flexibility to accommodate a number of scenarios using the same general framework for all the previously mentioned scenarios. Adjustments are either made in the Process Analyzer, through the matrix of input parameters, and/or directly in the model itself.

The simulation experiment results show that introducing two forms of viable competition, based on previous years' data and projected demands to the system, has a significant effect on both the T-AKE service level (the ratio of T-AKEs that leave the system to those that enter the system) and pallet throughput of the system. The impact of these effects holds true for the current system and the system that includes the new magazine on Orote Peninsula. T-AKE service level in the current system is reduced by an average value of 26% reduction in service level with a maximum value of 52%. This means that on average 1 of every 4 T-AKEs that enter the system is not serviced by the system. The T-AKEs not serviced at the end of the simulation time are left in queue. Pallet throughput is reduced by a maximum of 41,167 pallets and an average of 13,555 pallets. This reduction in pallet output is equivalent to approximately four T-AKEs' worth of ordnance that is not delivered to the forward edge of the contingency.

Regression analysis and partition tree analysis are used to analyze the simulation experiment results. Across the current and new systems, the primary critical factor for both is the T-AKE arrival cycle. A greater T-AKE arrival cycle input (less frequent arrivals) consistently causes the system to see a reduction in pallet throughput. The analytical results also suggest that setting the arrival cycle of the T-AKE and the Ordnance Container Ship (OCS) to the same interval, but with sufficient offset, reduces the impact of the competing requirements introduced to the system. The trade-offs to the optimal setting of the OCS and T-AKE arrival cycle are an increase in the number of containers offloaded from an OCS and a significant reduction in the number of containers unstuffed at Kilo Wharf.

Both competing requirements are contributors to the effects on the system, but never the most influential. The impact from competing ships was more often seen affecting the T-AKE service level, whereas competition for ordnance affected the overall pallet throughput. The analytical results suggest that, during a time of contingency, T-AKE service level is improved by implementing policies that result in the mean arrival rate of competing ships by more than one arrival every 30 days. It also suggests that keeping the competition for ordnance under 26% of the total containers offloaded improves pallet throughput.

Lastly, the analysis clearly shows that improving the system's performance is not dependent on the distance of ordnance storage facilities from the wharf, but rather in the volumetric capability of the system, as defined by available resources and specific policies. The results for the new magazine are not practically significant enough in the model, as compared to the current system, to justify a large infrastructure investment alone. However, safety requirements to the general public and our forces, with respect to ordnance on Guam, are factors not considered in this model, but are actually influence investment decisions.

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These last nine months of thesis work have been one of the more challenging and interesting periods of my life. First, I would like to thank God for this opportunity. I also thank God for blessing me with my wife, Michelle, and daughter, Natalie, who supported me during this mentally and emotionally challenging time. If not for your patience and unwavering support, this thesis may never have been completed.

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Finally, I cannot finish without acknowledging the guys in my Cohort, the "Seven Deuce." Gentlemen, you made this a fun ride!

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I. INTRODUCTION

> *My logisticians are a humorless lot...they know if my campaign fails, they are the first ones I will slay.*
>
> *Alexander*

> *It is in Asia where the United States will face its largest geopolitical challenges in the years ahead.*
>
> *Representative James Leach*
> *Former Chairman of the House Subcommittee on Asia and the Pacific*
> *September 21, 2006*
> *(Vaughn, 2007)*

As military campaigns evolve, there are a limited number of constants that hold true. One of these constants is the importance of sustainment and logistics capabilities. During a military crisis in which direct engagement is required, the ability to put ordnance on a target is vital to the concept of power projection. The underlying ability to sustain these operations is a logistics problem, which includes the continuous flow of commodities, such as ordnance, to the area of operation (AO). This logistics problem is equally important as the tactical problem, but often not as explored as the tactical application of targeting the ordnance. The responsibility then falls on the military logistician to study and explore the current and future possibilities of sustaining military actions. Consider if there were a modeling tool that exercised the possible options when such an event arises. Then, the decision maker would have a tool that could guide decision making, with respect to resource allocation, to effectively move ordnance through ports into an AO. This thesis studies the logistic capabilities of moving ordnance into the Asian Pacific Theater.

A. BACKGROUND AND MOTIVATION

In 2006, the United States Navy introduced its newest class of underway replenishment ships, the Auxiliary Dry Cargo/Ammunition Ship, Lewis and Clark Class

(T-AKE), to replace the aging combat stores and ammunition ships. This Combat Logistics Force (CLF) asset is designed to deliver ammunition, stores, and fuel to carrier and expeditionary strike groups (General Dynamics/NASSCO, 2007). These new ships will keep combatant ships at sea, on station, and combat-ready by providing a one-stop shopping source for replenishment. The combat logistics power of dry cargo/ammunition ships allows the United States Navy to provide critical logistics capabilities in today's dynamic maritime environment. The United States' ability to remain the preeminent naval power is enabled by our forward presence—our combat logistics ships are critical to this capability. The concept of operations (CONOPS) of this capability is illustrated in Figure 3. Shuttle ships cycle from resupply port to station ships, which serve as on-site logistic ships for a battle group. This CONOPS allows the battle group to travel freely, while maintaining a logistic line of communication for resupply.

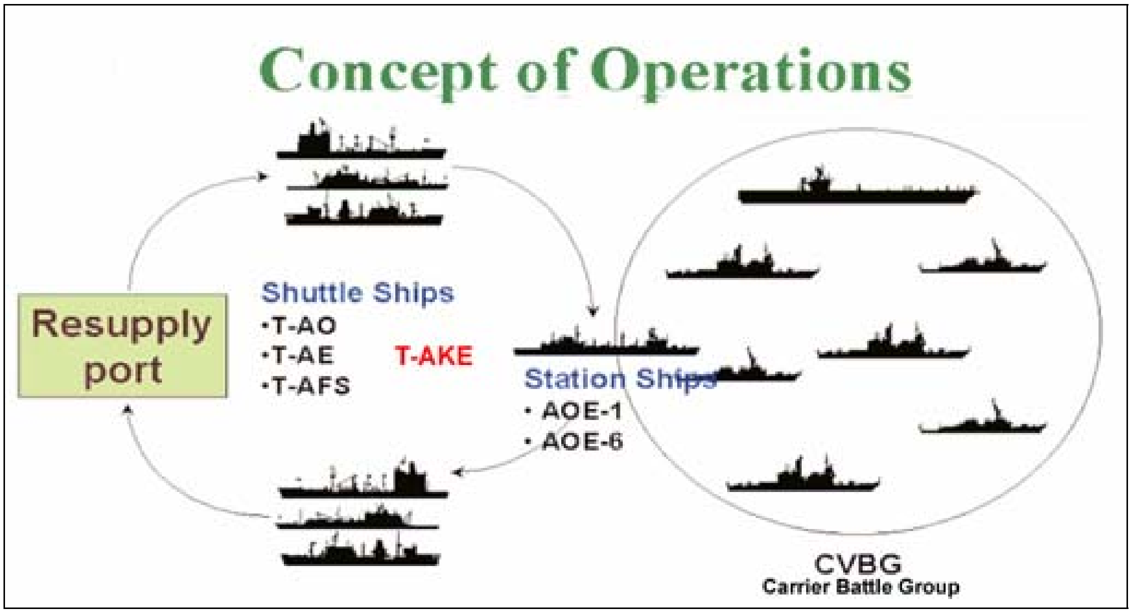

Figure 3. CONOPS for Battle Group Replenishment
(From: Markle & Wileman, 2001).

The question then becomes how to provide these vessels with the resources required to efficiently service our combatant ships. The forward-most port at which resources are received from the Continental United States (CONUS) and then readied for transfer becomes a key part of the answer to this question. Since forward presence and naval strength is predicated on the ability to put ordnance on target, this thesis focuses on the movement of ordnance into a theater of concern. The insights gained from this thesis may identify factors that improve the ordnance operations performance in ports of interest and provide indications of where equipment, personnel, and processes could be improved.

B. OBJECTIVES

The primary objective of this thesis is to conduct a thorough analysis, by use of simulation, into the capabilities and critical path scenarios of resupplying T-AKEs in Guam during a military contingency. It is done in partnership with Naval Surface Warfare Center, Carderock Division (NSWC Carderock) and the Director of the Strategic Mobility and Combat Logistics Division for the Chief of Naval Operations (OPNAV N42). In addition to the above, this thesis intends to provide recommendations for resource allocation and system flow path changes. A secondary objective is to provide a model that can be utilized in future analysis as a template for any given port.

C. BENEFITS OF THE STUDY

This thesis supports the Navy by conducting systems analysis of the major forward ordnance supply node of Asian Pacific Theater operations in an effort to answer the question: "How will introducing the competing requirements affect the predicted capabilities of the ordnance operations in Guam?" and "What are the critical factors in the ordnance operations process?" It incorporates the effects of competing requirements on the ordnance resupply process in Guam, specifically related to other Department of Defense (DoD) needs to utilize the ordnance wharf, as well as their increase in ordnance requirements. Previous studies have analyzed the capabilities of the island transportation infrastructure (Military Surface Deployment and Distribution Command [MSDDC], 2008), port operations pier-side (Goode & Smith, 2007), and optimization of the combat logistics force (Brown & Carlyle, 2007). This thesis combines some of the methods used in these approaches in an effort to provide a comprehensive model that moves ordnance from CONUS locations to the theater of interest. Additionally, this thesis produces a tool capable of being applied to other theaters of interest and future capability gap studies.

Current areas of interest for this type of research include infrastructure development, resource procurement and allocation, and policy decision-making processes.

D. METHODOLOGY

This thesis uses the discrete-event simulation package from Rockwell Software, named Arena, to model the port operations in support of resupplying T-AKEs in response to a military contingency in the Asian Pacific Theater. The focal point of the model structure is on the ordnance operations (specifically at the ordnance pier, Kilo Wharf) on Orote Peninsula, Guam. The available resources are varied within the simulation to account for differences in process performance characteristics and operations. The Arena modeling environment is a powerful modeling tool that enables the creation and running of experiments on models of systems. An Arena simulation has a framework that consists of an entity-based simulation that can be data farmed within a design of experiments (DOE) environment. This allows the simultaneous examination of multiple factors and explores the high-dimensional relationships of these factors. Through the use of an interchangeable, component-based architecture, the simulation provides the user with extensive capabilities to modify entities, configurations, simulation parameters, and data output. Arena, using a low-resolution approach, runs fast and is easy to set up. The Arena model can perform many analytical runs for comparison of more possible mixes.

This thesis uses a DOE approach to support the Navy analysis of forward logistic capabilities and provide quantitative analysis of problem feasibility. Use of the model provides data upon which analysis of the model is conducted, specifically looking at the effects of multidimensional, variable changes in an effort to estimate the impact on the frequency with which the CLF ships, particularly T-AKEs, could reload in Guam.

The DOE approach allows the user to vary a large number of factors simultaneously, and thus gain insight into the drivers of T-AKE resupply effectiveness and overall ordnance throughput. This enables the researcher to identify, compare, and contrast current methods and viable optional methods to optimize T-AKE reloading times and/or ordnance throughput, given a multitude of variable settings.

The flow of this thesis is as follows. Chapter II explains the model development and the assumptions used in the model. This includes introducing the scenario used in the model. Chapter III introduces the supporting data and methodology of the analysis applied to the simulation. Chapter IV presents the analysis and resulting insights. Chapter V provides conclusions and recommendations based on the analysis.

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II. SCENARIO DEVELOPMENT

A. INTRODUCTION

In order to provide military relevance to the analysis, a plausible scenario is explored. This chapter provides a brief introduction to ordnance operations, to include the offload, storage, and onload of ordnance. The scenario that follows is developed through a combination of previous studies and plausible forecasting. Following the scenario development is a description of the Arena simulation tool that is used to model and analyze the scenario. This chapter concludes with a detailed description of the behavior of the simulation model.

B. WHAT ARE ORDNANCE OPERATIONS?

1. Overview

In Chapter I, the term "ordnance operations" is introduced. As used in this thesis, ordnance operations describe a process of moving ordnance from CONUS to a theater of concern. In Figure 4, ordnance operations are simply illustrated as a flow path of processes. All of the terms below are thoroughly described in this chapter.

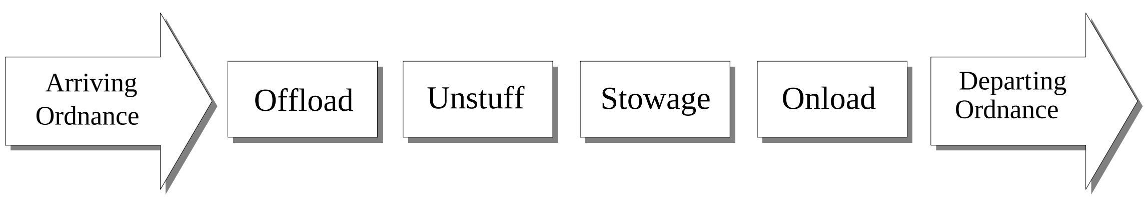

Figure 4. Ordnance Operations Flow Path Diagram.

2. Study Area Location and Facilities

Guam's location is significant as the western-most U.S. territory with the physical facilities capable of offloading, storing, and loading large amounts of ammunition. Figure 5 provides an aerial view of the thesis study area.

Figure 5. Map of Orote Peninsula Area, Guam (From: Goode & Smith, 2007).

This thesis focuses on the ordnance operations that occur at the United States Navy Base, Guam. The base sits on Orote Peninsula near the mouth of Apra Harbor and includes the Kilo Wharf, Buoy 702, and the Ordnance Handling pad. The Ordnance Annex, another important location in the ordnance operation, is located on the south central part of the island, southeast of the Apra Harbor Naval Complex. This section will describe both locations and their roles in ordnance operations on Guam.

a. Kilo Wharf

Kilo Wharf is located at the entrance to Apra Harbor on the north side of Orote peninsula. It is the primary facility for ordnance loading and unloading. The wharf is able to accommodate a single ship at any given time. Ships carrying or handling large amounts of ordnance, such as CLF ships and aircraft carriers, must use Kilo Wharf because of the Net Explosive Weight (NEW) limit of three million pounds and

Explosives Safety Quantity Distance (EQSD) of 7,210 feet (MSDDC, 2008). Figure 6 is an aerial view of Kilo Wharf from a northeast perspective.

Figure 6. Aerial View of Kilo Wharf (From: MSDDC, 2008).

b. Buoy 702

Buoy 702, at the northern edge of outer Apra Harbor, is the designated anchorage for fuel and ordnance-laden vessels waiting to dock at Kilo Wharf. This anchorage serves as the only standby location for vessels with more than 25 short tons of explosives. If there is a requirement for immediate berthing of a vessel with more NEW than allowable in the inner harbor, then Naval Munitions Command (NMC) East Asia Division, Detachment (Det) Guam must request a waiver. Accumulation of these waivers is not considered good practice (Naval Message, 2007).

c. Ordnance Annex

The Ordnance Annex is approximately 8,800 acres, making it the major ammunition magazine on Guam. The annex is also the location of NMC East Asia Division, Det Guam, and the joint venture formed by Day and Zimmerman Services Inc., SKE Support Services Inc., and Parsons Infrastructure and Technology Group Inc. (DZSP) 21. NMC East Asia Division, Det Guam is the command responsible for ordnance operations on Guam, and DZSP 21 is the service contractor that provides ordnance management services to NMC East Asia Division, Det Guam. The annex has over 100 storage magazines, providing a total NEW capacity of greater than 57 million pounds. The annex also has 10 open storage/staging areas capable of handling approximately 725,000 pounds of ordnance. It is important to note that the travel route to and from Kilo Wharf is along public roads, and passes near residential areas and an elementary school. This exposes the local community to a portion of the ordnance operations—an inherently dangerous undertaking. Figure 7 is an example of the magazine facilities that are found at the Ordnance Annex.

Figure 7. Igloo Storage Magazine at Ordnance Annex (From: MSDDC, 2008).

d. *Ordnance Handling Pad*

The Ordnance Handling Pad is located approximately one-half mile from Kilo Wharf. Its purpose is to serve as an area to relieve the constraints of unstuffing on Kilo Wharf itself. The 40,000-square foot concrete pad, constructed with lightning protection, is capable of holding 30 to 35 Twenty-foot Equivalent Unit (TEU) containers when being used to unstuff containers. When used strictly as a storage space for overflow containers, the pad stores up to 200 TEUs. Figure 8 is an image of the Ordnance Handling Pad that includes one of the corner posts used to elevate exposed cables for lighting protection.

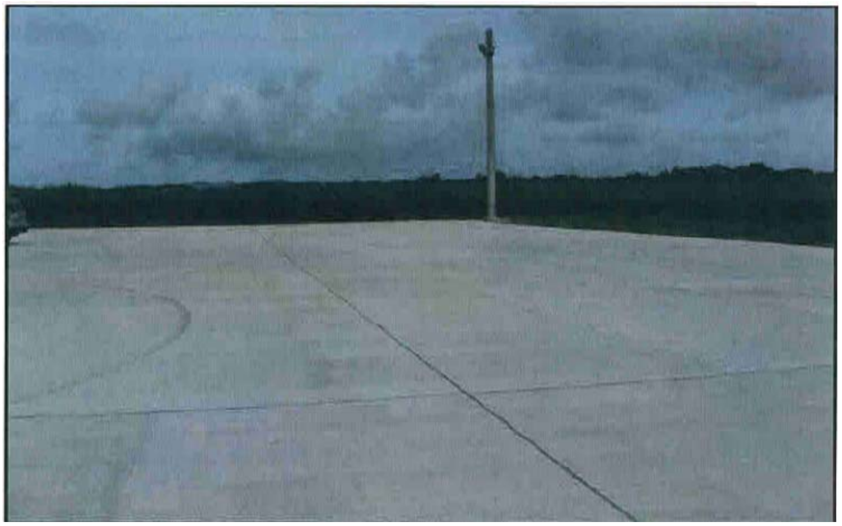

Figure 8. Ordnance Handling Pad at Orote Peninsula (From: MSDDC, 2008).

3. Operations

Ordnance operations begin with incoming containerized ordnance arriving on container ships from CONUS. The next stage in the process is the subsequent unloading of the containers to the pier, at a wharf that is qualified to handle ordnance. After the containers are unloaded, they are subject to a number of processes. One of these processes is simply transportation to an end destination, where they complete the portion of the process that this thesis covers. All Navy CLF vessels are designed as break-bulk ships carrying only palletized material. Therefore, the Navy does not deliver containerized ordnance to the combatants and all containers must be open and emptied (Goode & Smith, 2007). This process is known as unstuffing. This process may occur at the pier itself or at another location after a container has been transported to an authorized location. Once the unstuffing process is complete, the next process is stowage. In order to reach a stowage location, the palletized ordnance must again be moved to the stowage facility. Stowage is simply the retention of palletized ordnance in an authorized space. The last process of ordnance operations is the loading of the palletized ordnance, often referred to as the "onload." This occurs at the ordnance wharf, and involves loading the palletized ordnance onto a CLF vessel for delivery to combatants in the AOR. Figure 9 demonstrates the general flow process of ordnance operations. This thesis excludes the palletized stores portion of Figure 9, based on the requirement that no other operations occur during ordnance operations. Since all ordnance operations occur during the day, the result is that the stores loading operations take place at night. Therefore, the stores operation is assumed to not interfere with the ordnance operations and is thus outside the bounds of this thesis.

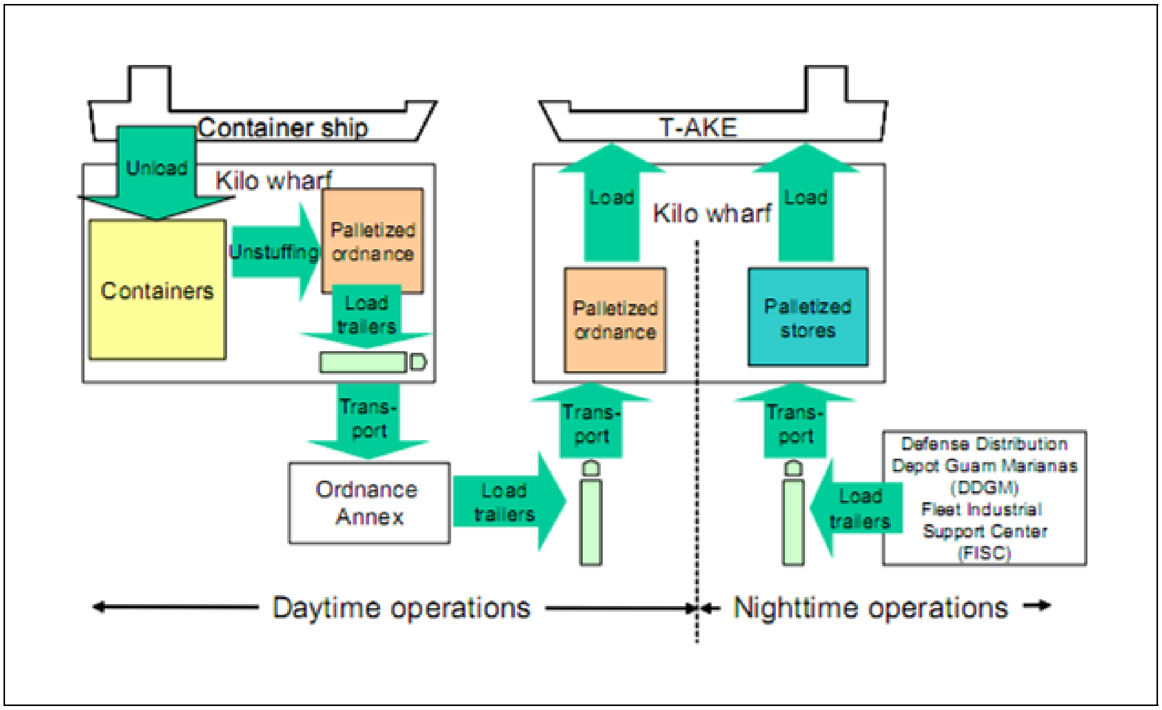

Figure 9. Ordnance Flow from Container Ship to a T-AKE Including the Dry Stores Component of any Replenishment Period (From: Goode & Smith, 2007).

a. Offload

The offload process commences when an ordnance-laden container ship arrives at the berth at Kilo Wharf. An ordnance-laden container ship is capable of carrying thousands of TEU containers. Each of these containers is estimated to carry between 12 and 14 pallets, which is equivalent to a standard ordnance load for a TEU of 13.9 short tons (Goode & Smith, 2007). The Kilo Wharf does not have an organic container crane, so arriving vessels are required to have their own crane(s) for offloading containers. Once pier-side, the containers are offloaded to the pier. At that point, container disposition could be conducted using one of three options. First, the container is moved onto the pier to an adjacent area for unstuffing. Second, the container is moved to a nearby ordnance-handling pad. Third, the container is moved to the Ordnance Annex for handling. Lastly, the container is delivered to Andersen Air Force Base (AAFB), located on the north end of Guam. Table 1 shows offload rate data (Goode & Smith, 2007 and MSDDC, 2008).

Table 1. Offload Rates (From: Goode & Smith, 2007, and MSDDC, 2008).

	Offload rate		Days to offload[a]
Estimate based on:	Containers/day	stons/day	
2003 study	45	625.5	6
TurboCADS 05	51	708.9	5
PacFlt planning factor[b]	75	1042.5	4
MSDDC Guam Ammunition Distribution Study[c]	95	1226.1	3[d]

a. Rounded up
b. Used to determine personnel augmentation from Expeditionary Logistic Support Force (ELSF)
c. Determined by simulation
d. Extrapolated using CNA report data

b. Handling (Unstuffing)

Unstuffing is done in conjunction with an inspection and inventory of the ordnance that is removed from each container. The ordnance units that are removed from the containers are in pallets. This thesis only considers ordnance to the smallest unit of pallet. In this thesis, all Navy containers of ordnance will be unstuffed, and all pallets inspected and inventoried as a part of the handling process. The inventory and inspection can only be done by qualified personnel. This adds a constraint to the palletized ordnance process flow.

Handling done at AAFB is considered outside of the bounds of this thesis, but will be modeled for continuity and accountability of all incoming ordnance. Containers designated for the Air Force are moved to AAFB and complete their flow path. The only impact to the ordnance operations caused by these containers is the amount of resources required to transport the containers. See Table 2 for the container unstuffing rates and days to unstuff 3,450 short tons (one T-AKE load equivalent) (Goode & Smith, 2007).

Table 2. Unstuffing Rates (From: MSDDC, 2008).

Number of containers unstuffed simultaneously	Inspectors per container	Containers per day	Stons/day	Days to unstuff[a]
	Unstuffing rates			
1	1	6	83.4	43
1	9	24	333.6	11
2	9	48	667.2	6

a. Rounded up

c. Moving Ordnance

Both containerized and palletized ordnance must be moved to a storage location at particular points in the ordnance operation process. Containerized movement requires both a Container Capable Forklift (CCF) and a Container Capable Truck (CCT). The CCF is required for movement on the Kilo Wharf and for loading to the CCT for transport. Currently, there are two operational CCFs available for ordnance operations at Kilo Wharf. Containerized movements occur from the wharf to the annex and to AAFB. Movements to AAFB can occur in three possible routes, whereas movements to the annex are by a single route. Palletized movement requires that the ordnance must be secured to a Pallet Transport Truck (PTT) by building a frame around the pallets, also known as block and brace loading (Goode & Smith, 2007). Palletized movements are generally between the wharf and the annex in both directions. Table 3 provides the distance set and estimated travel times.

Table 3. Movement Distance (in statute miles) and Travel Times (From: MSDDC, 2008).

Movement	Distance Min	Max	Average Travel Time
Kilo Wharf -- AAFB	25.1	29.1	50 - 75 minutes
Kilo Wharf -- Ordnance Annex	7.3	--[a]	25 - 35 minutes

a. No min and max because only one possible route.

d. Stowage

Ordnance stowage is carried out primarily at the Ordnance Annex. Ordnance is occasionally stowed on the Kilo Wharf or at the Ordnance Handling Pad while awaiting handling. All ordnance stowage is constrained by NEW limits and EQSDs.

e. Onload

Once pallets are delivered to the wharf from their stowage location, the loading process, called the "onload," begins. Onload requires ordnance material handling equipment (MHE) to load ordnance onto the T-AKE. The average onload rate calculated by the Center for Naval Analyses (CNA) in previous studies was 69.25 pallets per hour. Using a nominal weight of one ton per pallet, the rate for a 12-hour workday would be about 831 short tons of ordnance (Goode & Smith, 2007). Without access to the data used to make these calculations, the standard deviations are not available; therefore, these values are used in the model with a uniform distribution that varies slightly from the estimated rates.

C. SCENARIO DESCRIPTION

1. Overview

When conducting a simulation study, it is imperative to use realistic scenarios that allow the analyst to measure factors of interest in a way that is sensible to decision makers. Logistics planning is often done in advance of any known military contingency. This is done to ensure logistic capability gaps are discovered prior to any action. In order to draw on a plausible scenario, the basic outline for the scenario was obtained from two previous studies. The first was done by the CNA in 2007, at the request of the Director of the Strategic Mobility and Combat Logistics Division, to estimate the flow rate of supplies, with emphasis on ordnance, through Guam in surge conditions. The second study was conducted by Military Surface Deployment and Distribution Command (MSDDC), Transportation Engineering Agency in 2008. The purpose of their study was to conduct an assessment of Guam's transportation infrastructure and the ordnance operations in Guam under surge conditions. The purpose of this section of the thesis is to relate that scenario to potential consumers of this research. This provides a strong foundation for why this thesis is applicable to the Navy. The following is a brief synopsis of the scenario that forms the basis of the simulation model.

2. General Situation

The scenario established in this thesis is that the United States has become involved in a major military contingency in Asia and that T-AKEs are supporting the sea-based operation of a Maritime Prepositioned Force (MPF) squadron and its Marine Expeditionary Brigade (MEB) ashore. During such a contingency, the flow of supplies through Guam to forces at sea, or forces supported from the sea, is of critical importance. In order for T-AKEs to support only the sea-based operation of an MPF squadron and its MEB ashore, earlier studies have estimated how often they might have to go to port for resupply (Goode & Smith, 2007). In the case of a major military contingency, T-AKEs would also be supporting Carrier Strike Groups and other naval units. This translates to increased traffic intensity at the resupply port supporting the T-AKEs.

This increased traffic intensity is driven by the increase in demand for logistic support of ordnance. In order to meet this demand, more material must be shipped from CONUS to Guam to replenish the stock on Guam that diminishes as the demand of the combatants is met. The ordnance shipped from CONUS is delivered to the berth at Kilo Wharf in Guam. Once delivered, the ordnance is unloaded and processed pier-side. Occurring in the same period, the T-AKEs are arriving at Kilo Wharf to pick up ordnance for deliver to meet combatants demand. This again increases the traffic intensity seen by the forward logistics port. To complicate the scenario, yet also add a realistic approach to it, this thesis includes the competing requirements for use of the wharf by vessels other than the ordnance container ships and T-AKEs. Figure 10 illustrates the general flow of ordnance into the Asian Pacific Theater via Guam.

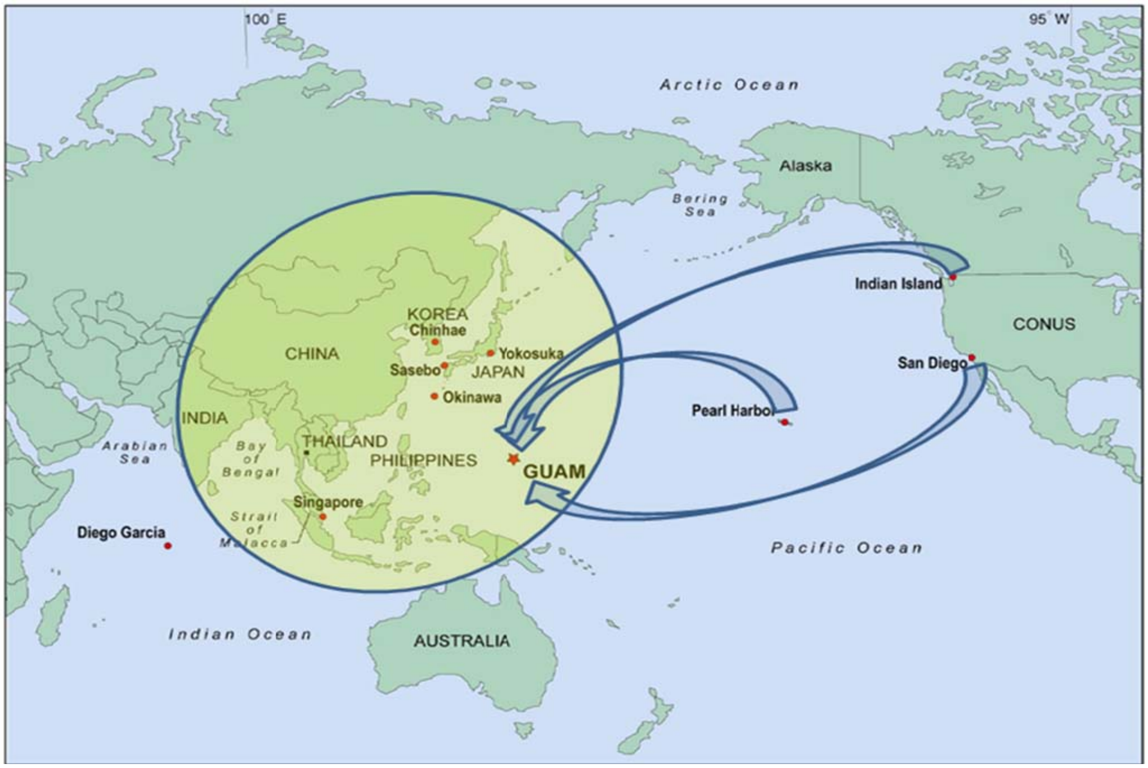

Figure 10. Area of Operations and Flow Paths of Inbound Ordnance. Note: The flow paths of incoming ordnance are based on the sources of ordnance supply (After: Helber, Hastert, & Fee, 2003).

D. THE ARENA SIMULATION TOOL

Now that the scenario has been described, this section describes the Arena modeling and simulation environment, a tool for creating entity-based, process-driven simulations, and why it was chosen. In Chapter III, the implementation of the scenario in Arena is covered. Readers interested in a detailed technical description of the software should consult the textbook *Simulation with Arena* (4^{th} Ed.) by Kelton, Sadowski, & Sturrock (2007) or the user's manual, which can be downloaded from the Rockwell Automation Website at http://www.arenasimulation.com/.

1. Why Arena?

Arena is the modeling environment selected for the development of the logistics process used in this thesis. The Arena modeling and simulation tool was chosen because of its focus on process improvement, ease of use, and applicability to logistics problems. It is a commercial product based on the SIMAN simulation language developed in 1983 by Systems Modeling Corporation, who also developed Arena in the mid-1990s. Systems Modeling was acquired by Rockwell Software in 2001 and they still support and develop Arena. Arena is simple in design; thus, any process that can be described by means of a flowchart can be simulated with Arena. As a modeling tool, it is very effective when analyzing manufacturing processes or flows. Arena was also chosen because it provides 2-D model animation. This feature is instrumental in the demonstration of the model in the debugging process. Providing visual support of process flow modeled in the simulation enhances credibility and ease of understanding for decision makers.

The Arena software lends itself to modeling a variety of scenarios involving queuing processes. Recent applications of the Arena software include Naval Postgraduate School (NPS) theses and projects that analyze real-world applications, such as homeland defense research, unmanned aerial vehicle material reliability, and maritime interdiction operations. Contact information for readers interested in more information regarding Arena is found at http://www.arenasimulation.com/support.

2. Characteristics of the Arena Simulation Environment

Arena is a discrete event-driven, entity-based simulation environment that provides an intuitive, flowchart-style environment for building an "as-is" model of a process (Rockwell Automation Inc., 2005a). Arena simulation software is an effective modeling tool when analyzing complex, medium- to large-scale projects involving logistics, distribution, warehousing, and service systems. Arena provides the user with the ability to create custom templates for complex, repetitive logic; to simplify model development; and reduce model development time. In addition, Arena is used to create customized simulation modeling templates focused on specific applications or industries

(Rockwell Automation Inc., 2009). Arena is also easily capable of performing data farming techniques, which give it the ability to explore many input parameters.

E. CHARACTERISTICS OF THE SIMULATION MODEL

This section describes the basic characteristics of the Arena simulation model developed for this thesis. It starts with a description of the simulation's goal, followed by an overview of the model at a conceptual level. Following the conceptual description are detailed descriptions of the component modules in the model. A detailed breakdown of the functional specifications of the model is contained in the Appendix, Functional Specification.

1. Goals and Measures of Effectiveness (MOEs)

The simulation models the military contingency scenario in this chapter as the sustainment of one year of operations. The length of the simulation run is easily adjustable for modeling longer or shorter periods of sustained operations. The ultimate goal of the simulation is measuring the impact of competing requirements on the effectiveness of ordnance operations in Guam. These competing requirements come in two forms:

- Competition for the wharf space by vessels not engaged in either the offload or onload of ordnance.
- Competition for the ordnance offloaded from the Ordnance Container Ships (OCSs). The Air Force will need to replenish their diminished munitions as well. Therefore, as an approximation, a percentage of the incoming ordnance loads will begin to be diverted to the Air Force. The Air Force requirements in the model are also a proxy for all other DoD requirements the system could possibly face.

The MOEs that are used in this thesis are T-AKE Service Level (the ratio of T-AKEs that enter the system to those successfully served by the system) and overall ordnance throughput (measured as the number of pallets that leave the system). These MOEs directly relate to the combat effectiveness of the combatants because as the customer they dictate the operational demand for ordnance. Other measures of interest include, but are not limited to, the following: time in queue for entities, number of containers of ordnance processed, number of pallets of ordnance processed out, equipment utilization, and resource utilization. Using data farming techniques allows for analysis of these and other factors.

2. Conceptual Model

The overall concept of the simulation model is represented as an inventory queuing model. A basic queuing model consists of customers who arrive for a service, servers who provide the service, an inventory available to the servers, and a warehouse where additional inventory is stored. In this model, the customers are OCSs, T-AKEs, and Competing Ships (CSs). The model considers the OCSs and the T-AKEs as primary customers because impacts to their operations will directly affect the combat capability of the fleet combatants. Although they are secondary customers, the CSs are not ignored because they are a realistic component in the model. The service that all vessels require is twofold. The required primary service is use of the wharf. The required secondary service is based on customer (ship) type. Successful service of an OCS is complete delivery of its ordnance load. This will increase the inventory level maintained at the Ordnance Annex (warehouse). Likewise, a T-AKE that receives its requested ordnance load is a successful service. This will decrement the inventory maintained at the annex. This thesis considers maximum service of T-AKEs as optimal. Successful CS service is simply usage of the wharf and departure. The server is a combination of the Kilo Wharf and the ordnance operations required by the particular ship at the server. An effective service is considered to be a vessel served and, therefore, that MOE is the number of a particular vessel type served, divided by the total number of vessels to enter the system. In other words, the effectiveness of the process in its entirety is measured by how well its primary customers are served.

3. Key Components of the Model

This section describes some of the key components found in Arena simulation models, with emphasis on components widely used in this thesis.

a. Entities

Entities represent the objects moving through the system. Entities are built into the system using the Create Module. Each entity has its own characteristics, referred to as *attributes*. An entity is assigned as many attributes as required for the different types of entities in the system. Each individual entity in the system has its own values of these attributes; these may be assigned at the various processes it encounters (Rockwell Automation Inc., 2005b). The assignment of attributes for entities is accomplished through an Assign Module. Figure 11 represents a Create Module and associated graphic user interface (GUI), which allows for specific entities to be created and enter the system.

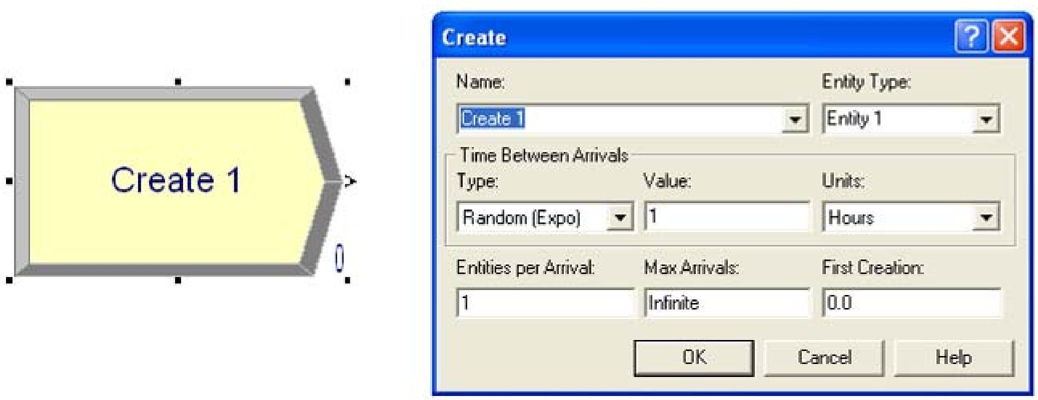

Figure 11. The Create Module and Create GUI in Arena.

For example, all ships entering the model in this thesis are immediately given a minimum of two attributes. The first attribute is to indicate the time they entered the system, *a_Arrival_Time_to_System* with the current value of "time now" (TNOW), the current simulation time. The second attribute is a type identifier, *a_Ship_Type*, which simply indicates the type of ship entering the system. These attributes are later used by the model as a part of the process logic. Figure 12 represents the Assign Module and Assign GUI that allows for specific entities to be assigned attributes that they carry through the system.

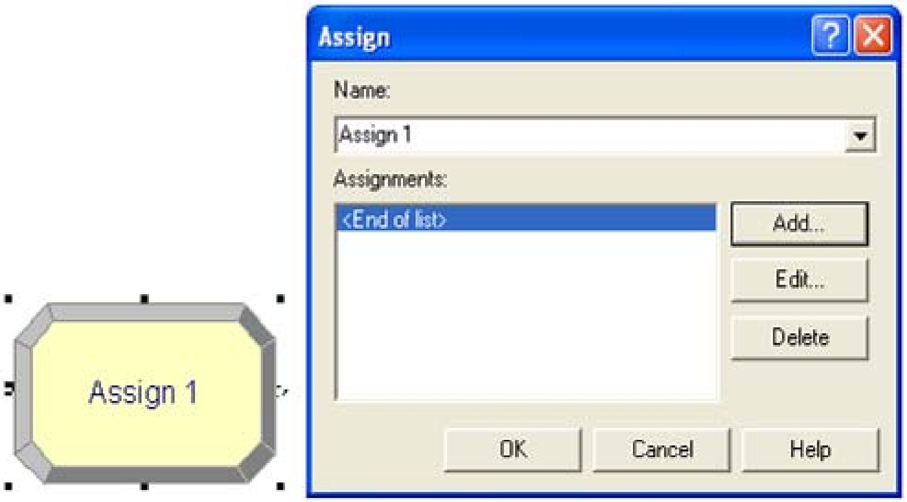

Figure 12. The Assign Module and Assign GUI in Arena.

b. Queues

The primary purpose of a *queue* is to provide a waiting space for entities whose movement through the model has been suspended due to the system status (e.g., a busy resource). Queues are passive in nature; entities enter the queue and are removed from it based on the change in state of the system element associated with the queue (e.g., a resource) (Rockwell Automation Inc., 2005b). An example of a queue in this thesis is the one that is formed when the *Kilo Berth* resource is occupied. Figure 13 represents a Process Module and its associated Queue GUI. The process module is where queues are generated to indicate where an entity will wait, if required, for resources to complete the defined process.

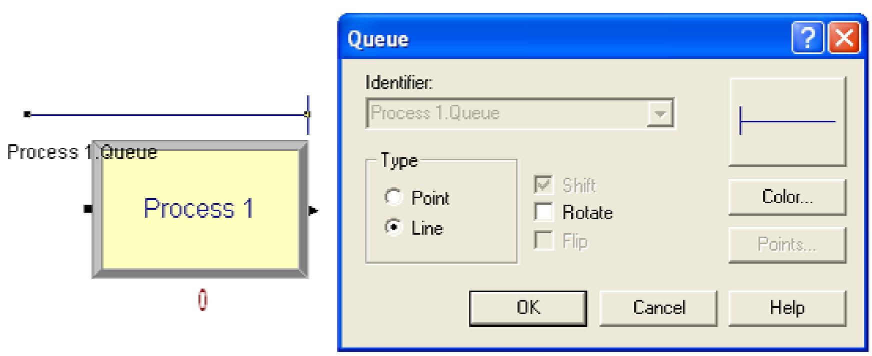

Figure 13. The Process Module and associated Queue GUI in Arena.

There are two types of queues used by Arena. *Individual queues* have a *symbolic name*, a *ranking rule*, and a specific *capacity*. Entities in these queues may be displayed in the animation; statistics may be collected on them; they may be ranked using a flexible ranking rule mechanism; they may be collected into sets; and, when used with resources, they may be shared among modules (Rockwell Automation Inc., 2005b). *Internal queues* provide a basic first-in, first-out container for entities at a particular activity (module), but do not provide animation, statistics, or ranking mechanisms (Rockwell Automation Inc., 2005b). The queue of interest in this thesis is the queue for entities entering the system and is unlimited. This queue is discussed further in Chapter III.

c. Resources

Resources are stationary elements of a system that can be allocated to entities. They have a specified *capacity* (at any point in time) and a set of *states* (e.g., busy, idle, inactive, or failed) that they transition between during a simulation run. Resources may be used to represent people, machines, or even space in a storage area. In this thesis, resources include all three of the possibilities mentioned; ordnance inspectors, cranes, and storage and processing space. The terminology associated with resources is as follows: when an entity requires a resource, it *seizes* the resource; and when an entity no longer requires a resource, the entity *releases* it so that it is available to be seized by other entities. A resource has an associated queue to hold entities that try to seize the resource when it is unavailable (Rockwell Automation Inc., 2005b). An entity in the queue waiting for a resource will immediately seize the resource once available. Any transitional delays in resource seizure are accounted for in the process delays. Resource information is maintained in a data module as seen in Table 4. This data table allows the user to define the type and capacity of any given resource in the system.

Table 4. The Resource Data Module in Arena.

Resource - Basic Process

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use
1	Kilo Berth	Fixed Capacity	1	0.0	0.0	0.0
2	Buoy 702	Fixed Capacity	1	0.0	0.0	0.0
3	Ordnance Annex Magazine Storage	Fixed Capacity	99999999	0.0	0.0	0.0
4	Crane	Fixed Capacity	2	0.0	0.0	0.0
5	Pierside Staging Space	Fixed Capacity	2	0.0	0.0	0.0
6	Container Truck Loading Space	Fixed Capacity	2	0.0	0.0	0.0
7	Ordnance Inspector	Fixed Capacity	18	0.0	0.0	0.0
8	Unstuffing Space	Fixed Capacity	120	0.0	0.0	0.0
9	Block and Brace Crew	Fixed Capacity	10	0.0	0.0	0.0
10	Ordnance Forklifts	Fixed Capacity	20	0.0	0.0	0.0

Double-click here to add a new row.

The capacity of a resource limits the number of entities that may seize it at any point in time. For instance, the wharf is a resource in the model that can only accommodate one ship. It is represented by a resource called *Kilo Berth*, having a capacity of one. An entity that seizes a resource is referred to as seizing a *unit* from its total capacity. Entities can seize and release multiple units of capacity (Rockwell Automation Inc., 2005b).

d. Stations

Systems typically have natural boundaries that suggest a systematic segmentation approach in forming their representation. For example, a manufacturing system is usually composed of a set of distinct workstations. Multiple workstations may then form a manufacturing line, and multiple lines form a manufacturing site (Rockwell Automation Inc., 2005b).

Arena allows you to represent systems by first dividing them into the physical subsystems, referred to as *stations*, where the actual processing takes place. Thus, for example, each workstation in a manufacturing model can be represented by a station in Arena (Rockwell Automation Inc., 2005b). Figure 14 represents the Station Module, which provides the method for defining physical subsystems and process boundaries.

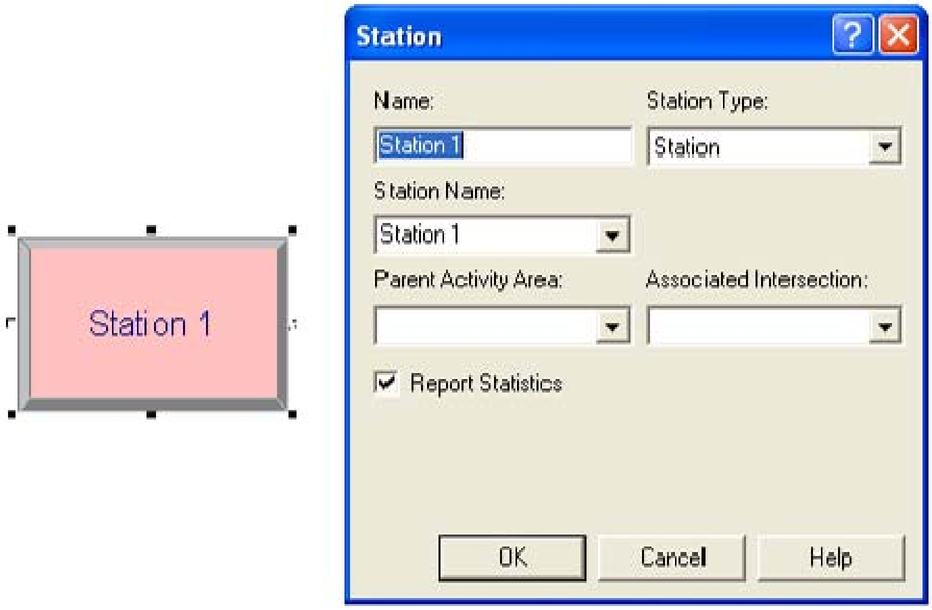

Figure 14. The Station Module and Associated Station GUI in Arena.

e. Transporters

Transporters are one type of device that moves entities through the system. They can be used to represent material-handling or transfer devices, such as fork trucks or delivery vehicles. Transporters can also be used to model personnel whose movement is important to modeling a system, such as a nurse or a food server. When transporters are used, you provide information defining the transporter's speed and the travel distances between stations served by the transporter (Rockwell Automation Inc., 2005b).

The terminology associated with transporters is as follows: When an entity requires a transporter, it *requests* the transporter; then it is *transported* to its destination station (both transporter and entity move to the station together, and the entity enters the model at the module containing the destination station); and when the entity no longer requires a transporter, it *frees* the transporter (Rockwell Automation Inc., 2005b).

Animation transporter pictures show the movement of free-path transporters from station to station or of guided transporters from intersection to intersection. All transporters in this thesis are free-path transporters. Transporters can be idle, busy, or inactive, with different pictures for each state. Movement of free-path transporters occurs only between defined *distances* connecting *stations* (Rockwell Automation Inc., 2005b). Table 5 is an example of the transporter data module that defines the number, type, and velocity of each specific transporter.

Table 5. The Transporter Data Module in Arena.

Transporter - Advanced Transfer

	Name	Number of Units	Type	Distance Set	Velocity	Units
1	Container Capable Forklift	2	Free Path	Container Capable Forklift.Distance	26400	Per Hour
2	Container Truck	8	Free Path	Container Truck.Distance	12	Per Hour
3	Pallet Transport Truck	12	Free Path	Pallet Transport Truck.Distance	12	Per Hour

Double-click here to add a new row.

4. Arena Simulation Time

Since Arena is an entity-based simulation model, time advances only as directed by the entities as they encounter the models component modules. For example, if a process is defined to take a certain amount of delay to be complete, then the simulation will advance time when activated by an entity. That entity completes the process and moves on when that specific delay completes. A simple way to describe this type of modeling is to imagine walking the path of the process that is model. If along the path you encounter a process module that takes one day to complete, you will stay at that module for one day. Thankfully, Arena is able to advance time rapidly in its simulation process and thereby move a multitude of entities through a variety of processes that mirror real time delays.

The Run Setup mode, as seen in Figure 15, provides a variety of setting options for application to the user’s specific system such as project parameters, run speed, replication parameters, run control, array sizes, and reports defined in the model.

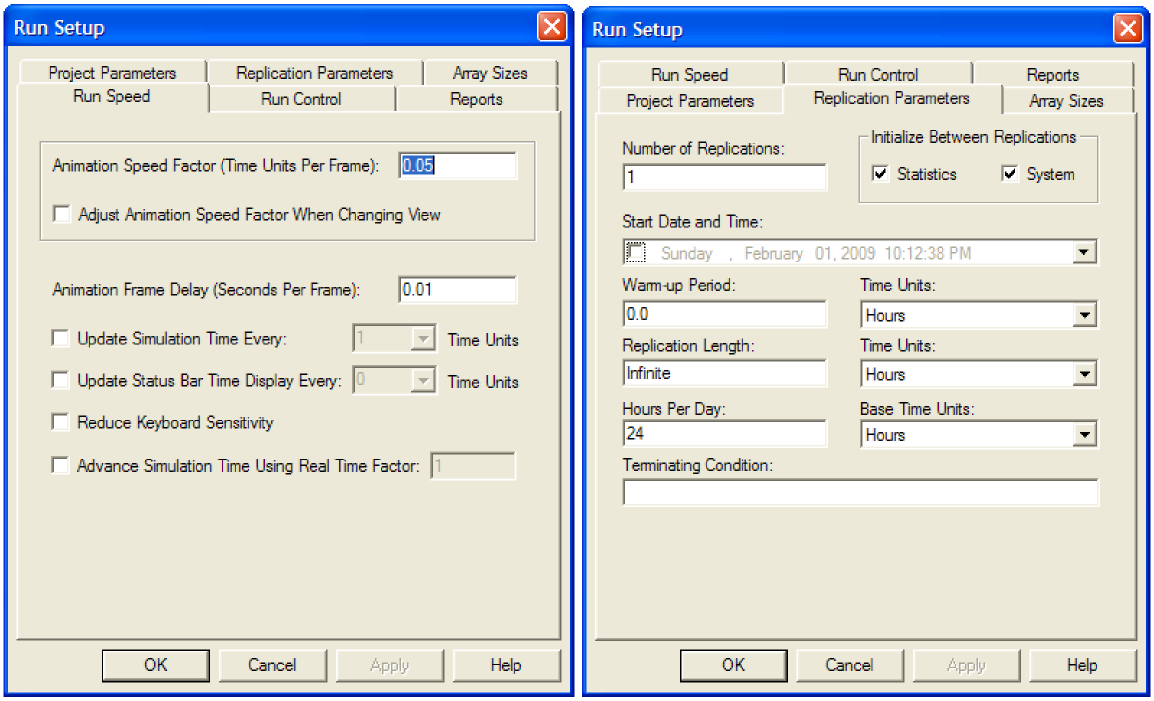

Figure 15. The Run Setup Menu in Arena.

5. Summary

This thesis uses the Arena simulation tool to model realistic ordnance movements into an AOR through a forward supply node. The scenario used in this model was chosen because of its high visibility among logistic planners and because it is logistically challenging. The resulting model captures the essential components of ordnance movement and the operations necessary to gain insight into the effectiveness of the system when affected by competing requirements.

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III. MODEL IMPLEMENTATION AND EXPERIMENTAL DESIGN

A. INTRODUCTION

This thesis makes use of a technique known as data farming, which was developed and used by the Simulation, Experiments, & Efficient Designs (SEED) Center at the Naval Postgraduate School (see http://harvest.nps.edu/). This technique provides the analyst with methods to explore the possible inputs in a more efficient manner. Specifically, the technique involves taking a simulation and running it many times, while simultaneously changing the input parameters. As the number of input parameters in the simulation increases, the analyst becomes challenged with the “curse of dimensionality,” a term coined by renowned applied mathematician Richard Bellman. This term describes the problem caused by the exponential increase in volume associated with adding extra dimensions to a (mathematical) space (Bellman, 1957). Data farming acknowledges this challenge. Instead of attempting to examine all the possibilities, data farming provides an output data set that allows the analyst to explore more of the landscape of possible outcomes in a mathematically intelligent fashion. This exploration leads to a better understanding of the initial problem and provides insight into which input factors, if any, have significant effects.

This chapter starts by outlining the primary entities involved in the simulation and their assigned attributes. This is followed by describing the resources of interest and the variables chosen as input parameters for the simulation experiment in this thesis. Finally, this chapter describes experimental designs used to generate the data used to understand more completely the effects of competition on moving ordnance into the Asian Pacific Theater through Guam.

B. PRIMARY ENTITIES AND ATTRIBUTES

The entity is the primary participant in an Arena simulation. The entity is what travels through the simulated process and utilizes resources available in the system. An entity receives its identity through the process of attribute assignment. The naming convention used in this thesis is that all attribute names begin with "*a_*" followed by the attribute name. This section describes each of these entity types and the attributes associated with each type. This thesis uses a total of five major entity types throughout the model: the Ordnance Container Ship (OCS), the TAKE Ship (spelled without the hyphen as a function of Arena-allowable naming conventions), the Competing Ship (CS), the Ordnance Container, and the Pallet. There is also one minor entity type, Entity 1, which is used in the system at the simulation finish time (TFIN). This entity is defined as minor because its only purpose is to initiate the *ReadWrite* process that writes the defined outputs to an Excel spreadsheet.

Of the five major entities, the three ship types of entities are the first active entities to enter the system. An initial inventory of pallets actually enters the system before any of these entities, but remains inactive until the first T-AKE arrival. Aside from the system initialization with an inventory of pallets, all other pallets are not created for direct input into the system. The Ordnance Container Entity and the Pallet Entity are both generated as entities that result from the arrival of an OCS Entity to the system.

The OCS Entity, as well the two other ship-type entities, is created at what would be considered the beginning of the process. Upon creation, the OCS Entity is immediately assigned a set of attributes.

- **Number of Containers On Board (*a_Num_Containers*)—**This is the number of Ordnance Containers carried by the OCS. As the primary source of ordnance supplies to the system, this is a vital attribute of the OCS. In reality, container ships are capable of carrying thousands of containers. This thesis makes the assumption that the OCS will unload approximately enough containers to supply a T-AKE. This number can be a predefined constant or a variable. Both methods of defining *a_Num_Containers* are used in this thesis. The constant method was used in the baseline scenario. The value assigned in the constant method is 255, and is based on the assumption that a T-AKE full load has the value of 3,540 short tons of ordnance. This value is approximately 70% of the possible ordnance load that a T-AKE could carry and purposely high to match the scenario requirement of supporting engaged combatants. Since the standard ordnance load for a TEU is approximately 13.9 short tons (Headquarters, Department of the Army, 1997), the calculation for a containers per T-AKE using these assumptions results in 255 containers.

The variable method is used in all other scenarios. The variable method uses a variable, *v_Cont_per_OCS*, which is discussed further in Section F defining the model variables.

- **Arrival Time to the System (*a_Arrival_Time_to_System*)—**This is a timestamp given to the OCS upon entering the system. Time-based statistics use this attribute assignment to calculate outputs, such as how long the entity is in the system.
- **Ship Type (*a_Ship_Type*)—**This is an attribute used to identify the ship type numerically. All OCSs are given *a_Ship_Type* assignment values of one (1).

The TAKE Ship Entity receives similar attribute assignments to the OCS in Arrival Time to the System and Ship Type. The Arrival Time to the System is entity-arrival dependent and the Ship Type value assigned to T-AKEs is two (2). The attribute of interest for the T-AKE is:

- **The Number of Pallets Needed (*a_Pallets_Needed*)—**This attribute is what defines the demand of the combatants involved in the contingency. The value of this attribute is the integer value of a triangular distribution with parameters, TRIA (3315, 3500, 3570). This distribution is based on the calculations for T-AKE load capacity and the likely load size assumption used to calculate *a_Num_Containers*. As T-AKEs are employed to the Fleet, better data for actual load size carried can be obtained and this distribution can be adjusted.

The CS Entity requires no distinctive attributes because it does nothing other than vie for a limited number of resources that the other ship entities require as well. Thus, the CS receives the attributes of Arrival Time to the System and Ship Type. The Arrival Time to the System is entity-arrival dependent and the Ship Type value assigned to CS is three (3).

The Container Entity is a product of the OCS and is generated by separating the containers from the OCS and then assigning them attributes specific to containers. These entities are not "created" like the ship entities. The Separate Module in Arena provides the mechanism for generating entities from a higher level entity. In this case, the OCS is the higher level entity from which containers are generated. Figure 16 shows the first step in this entity generation. The original OCS and a duplicate are separated, but the duplicate "inherits" the same attribute values of the original OCS. The duplicate is routed along a different path and eventually departs the system when it has completed all required processes. This duplicate entity embodies the OCS, which moors at Kilo Wharf to unload ordnance containers.

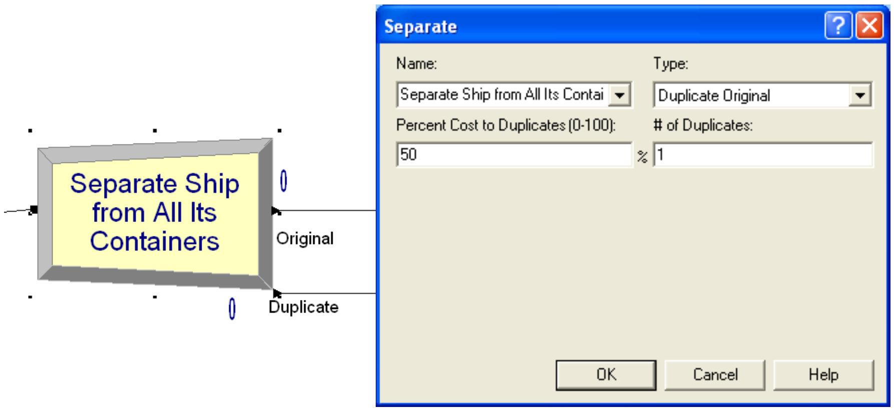

Figure 16. The First Separate Module for an OCS and Associated Separate GUI.

The next step in generating containers is to again use a separate module to duplicate the OCS. Before this happens, the intermediate OCS entity receives a variable assignment necessary to count the number of containers removed from the OCS. Once the variable assignment is made, the original OCS is separated into "*a_Num_Containers – 1*" containers and one original. The number of containers is decremented by one because the original and duplicates will both be given container attributes and sent along the same process path. Figure 17 shows the separation process used to generate Ordnance Container Entities from an OCS Entity in this thesis.

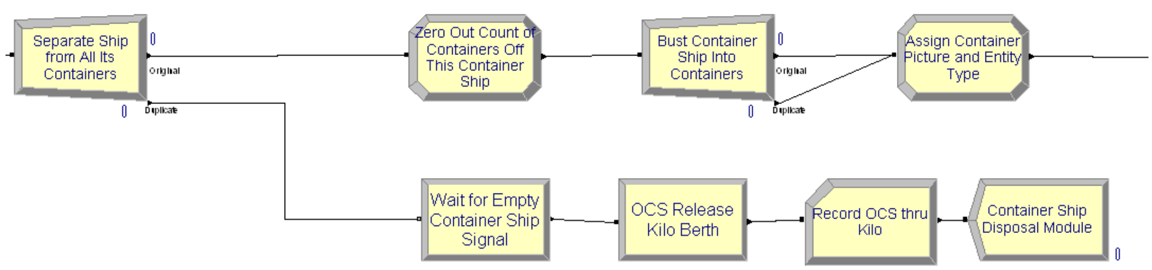

Figure 17. The Container Generation Segment.

Figure 18 shows the Assign Module used to give all of the newly generated containers their initial attributes. The entity picture is assigned to differentiate this entity type in the model animation. The entity type is assigned as "*Container*."

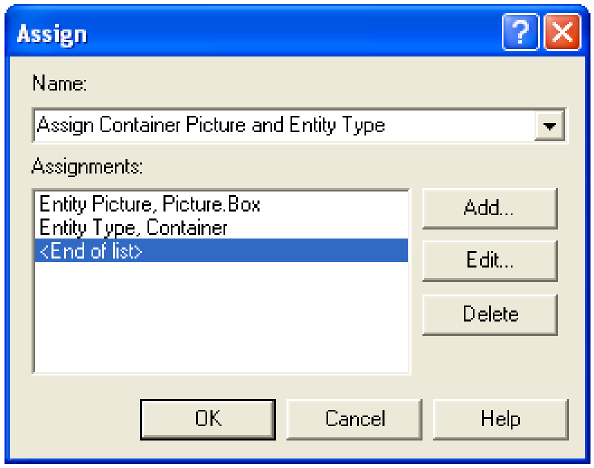

Figure 18. The Assign Module for a Container.

Containers receive four other attribute assignments types while in the system. The first is an assignment of ownership. One of the competing requirements used in this model is achieved here by giving each container a type of property stamp. The container can either be marked for the United States Navy (USN) or it can be marked for the United States Air Force (USAF). This assignment is determined by an input parameter *v_percent_Navy_Cont* that is described in Section F, defining the model variables. The attribute name used in this assignment is *a_Switch*. The attribute name is generic because it is used solely as a switch in a subsequent Decide Module to direct traffic.

Once the containers path is determined by *a_Switch*, the container can then be assigned a destination designator attribute, *a_Destination_Identifier*. This attribute has a value of either 777, designated to Andersen AFB, or 999, designated to the Ordnance Annex. All containers that are assigned to the USAF by *a_Switch* also receive *a_Destination_Identifier* value of 777. All containers assigned to the USN must encounter another attribute assignment before receiving their *a_Destination_Identifier*. This other attribute assignment given to containers is used similarly to the *a_Switch* attribute just described. In fact, because it performs a similar function to containers that have previously received an attribute named *a_Switch*, but at a different point in the process, it uses the same attribute name *a_Switch*. This particular *a_Switch* assignment is determined by an input parameter *v_percent_unstuffed_pier* that is described in Section

F, defining the model variables. This parameter determines where a container is unstuffed. Once this attribute is assigned, then the *a_Destination_Identifier* for this container is assigned a value of 999.

As mentioned earlier, the Pallet Entity is the very first type of entity created in this system. Figure 19 shows this inventory initialization done by a Create Module. These pallets have the same attributes as other pallets that are generated in the system.

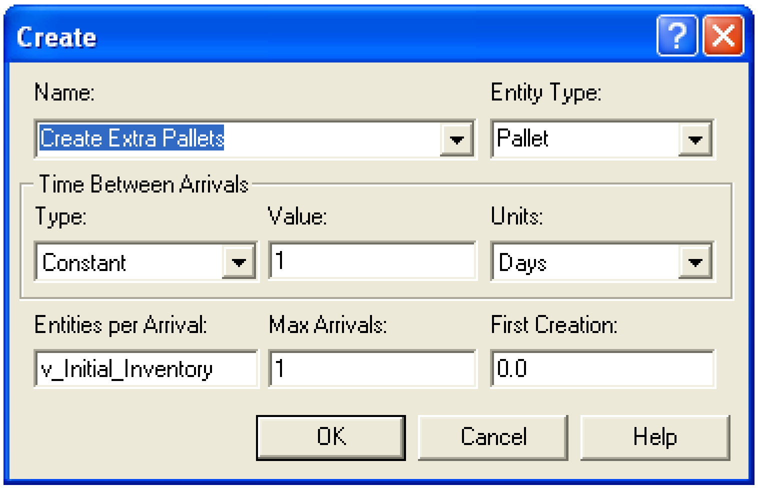

Figure 19. The Create Module for Initialization.

In order to establish an initial inventory on hand at the onset of the simulation, a Create Module is used once to generate an initial inventory defined as a variable, *v_Initial_Inventory*. A minimum *v_Initial_Inventory* value of 75,000 pallets is used in this model for any scenario that involves competing requirements. Reasons for this minimum value setting are discussed in Chapter IV. This initial inventory represents a portion of the ordnance Prepositioned War Reserve Material Stock (PWRMS) located at the Ordnance Annex. As the PWRMS depletes, a safety level is required to keep the system from experiencing shortages; this is what *v_Initial_Inventory* represents.

All other Pallet Entities are generated in a manner very similar to Container generation from an OCS entity. The biggest difference is that Pallets are generated from Containers and thus receive a different set of attributes. Figure 20 shows the Assign Module used to give the newly generated pallets at the Ordnance Annex their initial attributes.

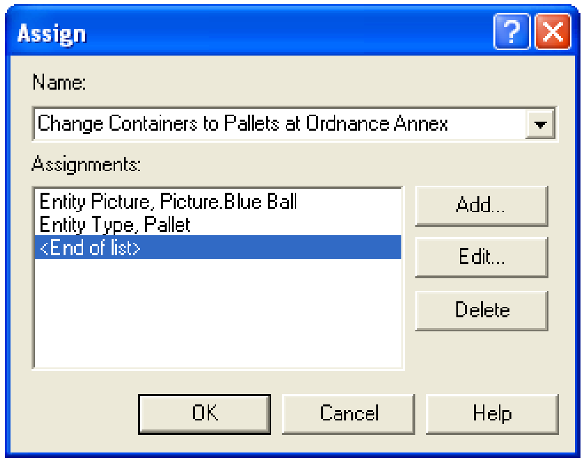

Figure 20. The Assign Module for Pallets at the Ordnance Annex.

The entity picture is assigned to differentiate this entity type in the model animation. The entity type is assigned as "*Pallet*." Pallet Entities are also generated at Kilo Wharf in the Unstuffing Area. These pallets are assigned the same entity type and picture.

C. PRIMARY RESOURCES

Resources are used to represent people, machines, or even space in a storage area. This section describes the resources used in this thesis, which include all three of the possibilities mentioned: ordnance inspectors (people), cranes (machines), and storage and processing space. In Arena, the capacity of a resource is a constant that cannot be changed unless using the Process Analyzer function. For this reason, this model was built with constant capacity values, based on existing resources. Changes to resource capacities are done by using the Control portion of the Process Analyzer. This technique is described in Section G of this chapter. A majority of the resources studied in this thesis are of the space variety. All space resources are described first, followed by personnel, and then equipment.

1. Space Resources

a. Kilo Berth

Kilo Berth is the primary single server berth used by all ship-type entities in this thesis. The capacity of this resource is defined as a constant, value of one (1), throughout the thesis.

b. Buoy 702

Buoy 702 is the single server standby location (anchorage) for all ship-type entities awaiting the opportunity to berth at *Kilo Berth*. The capacity of this resource is defined as a constant, value of one (1), throughout the thesis.

c. Pier-side Staging Space

Pier-side Staging Space is the space located directly on the pier that is used to place Ordnance Containers as they are offloaded from the OCSs. This resource is important to the process in that, if it is busy, containers cannot be offloaded from the OCS. The capacity of this resource is defined as a constant, value of two (2), throughout the thesis.

d. Unstuffing Space

Unstuffing Space is the space located at the Kilo Wharf adjacent to the pier and at the Ordnance Handling Pad. Combined, the two sites provide a constant capacity of approximately 120 spaces before unworkable. This approximation is based on the 100 spaces available at Kilo and the 30 to 35 available at the Handling Pad. Reducing the number by 10 to 15 leaves appropriate space for moving containers and pallets while unstuffing occurs.

e. Ordnance Annex Magazine Storage

Ordnance Annex Magazine Storage is the space available at the Ordnance Annex available for pallet storage. The capacity of this resource was set to be essentially unlimited for the purpose of this thesis. The model is built with the capacity of this resource defined as a constant, value of 99,999,999, throughout the thesis. In doing so, the initializing inventory level of pallets is used to determine if the current available space is sufficient to handle this type of contingency. If the initializing inventory required to run the model for the specified time period exceeds the current (and planned) storage capabilities, then this explicitly shows an infeasibility issue with the system as a whole.

For purposes of model flexibility, the *Ordnance Annex Magazine Storage* resource is also used to model the new magazine being built on Orote Peninsula in the last scenario set of the experiment. The assumption is that the new magazine will be the primary transition point for the inbound and outbound ordnance supported by the Annex located further away. By assuming the same properties as the Annex for the new magazine, the only factor that changes in this scenario set is the distance between the Kilo Wharf and the then Annex and now magazine. This is admittedly a generous assumption, but it follows the same reasoning used in the NAVBASE GUAM FY 2008 Military Construction Program Project P-425 document DD Form 1391, dated 01 August 2005, that identifies the requirement to build the magazine.

> IMPACT IF NOT PROVIDED
>
> Without construction of magazines on Orote Peninsula, the safe and efficient pre-positioning of ammunition near Kilo Wharf cannot be accommodated. As a result, the level of throughput envisioned for Guam will not be achieved. Whether ordnance arrives via container or break-bulk, the materials will need to be hauled to the Ordnance Annex for temporary storage, and transported back to Kilo Wharf for the next T-AE upload. The need to haul ordnance between the two locations constrains throughput operations and the efficient delivery of ordnance to the fleet. Anticipated increases in the operational tempo in the Pacific and Indian Ocean theaters will exacerbate the problem. (NAVBASE GUAM DD Form 1392, 2005)

f. Container Truck Loading Space

Container Truck Loading Space is the space located on the pier that is used to load Ordnance Containers to Container Capable Trucks for transport to either the Annex or AAFB. The capacity of this resource is defined as a constant, value of two (2), throughout the thesis.

2. Equipment Resources

a. Crane

The *Crane* is an equipment resource that is inherent to OCSs arriving for ordnance offload. Currently there are no *Cranes* organic to Guam that can safely and efficiently offload ordnance. The capacity of this resource is defined as a constant, value of two (2), throughout the thesis.

b. Ordnance Forklifts

Ordnance Forklifts are equipment resources that are part of the T-AKE loading process. Although these forklifts could technically be considered free-path transporters, they are modeled as resources in this thesis because their negligible distance traveled is between a loading spot on the pier and one of 100 possible unstuffing spaces. Modeling these as transporters would require approximately $100^2 = 10{,}000$ paths to be built into the model for such small distances. Instead, the forklifts are built into the model as resources that incur a delay that accounts for distance traveled when seized by pallets that are loaded to the T-AKE. The capacity of this resource is defined as a constant, value of 20, throughout the thesis. This value assumes a slight increase in the assets listed in the CNA Report CRM D0017313.A1 (Goode & Smith, 2007), based on the scenario from 14 to 20 forklifts.

3. Personnel Resources

a. Ordnance Inspectors

Ordnance Inspectors are personnel resources instrumental to the unstuffing process. *Ordnance Inspectors* inventory and inspect all pallets of ordnance unstuffed from a container. Delays incurred by the inventory and inspection process are built into the *Ordnance Inspectors*. The capacity of this resource is defined as a constant, value of 18, throughout the thesis (Goode & Smith, 2007).

b. Block and Brace Crew

Block and Brace Crews are personnel resources instrumental to the pallet transport process. *Block and Brace Crews* ensure load stability of pallets transported by building a frame around the pallets. Delays incurred by the block and brace process are built into the *Block and Brace Crews*. The capacity of this resource is defined as a constant, value of 10, throughout the thesis. This value is set at just higher than 80% of the number of trucks able to transport pallets. This is done to ensure that a block and brace crew is available for pallets that are ready to be loaded, while the other 20% of the pallet trucks are in transit. This is also a generous assumption, but very feasible to achieve.

D. PRIMARY PROCESSES

A *process* in this thesis describes the action taken by an entity throughout the system. These processes are all directly related to the resources just described in Section C of this chapter. Figure 21 represents the GUI associated with an Arena Basic Process Module and displays the four types of action that a Basic Process can perform: Delay, Seize Delay, Seize Delay Release, and Delay Release. Advanced Processes are also available for use in the model. These consist of the individual actions listed in the Basic Process Module, except as the separate modules: Seize, Delay, and Release. This section describes and explains the major processes built into the thesis model. The processes are divided into categories based on the entity that is carrying out the identified process.

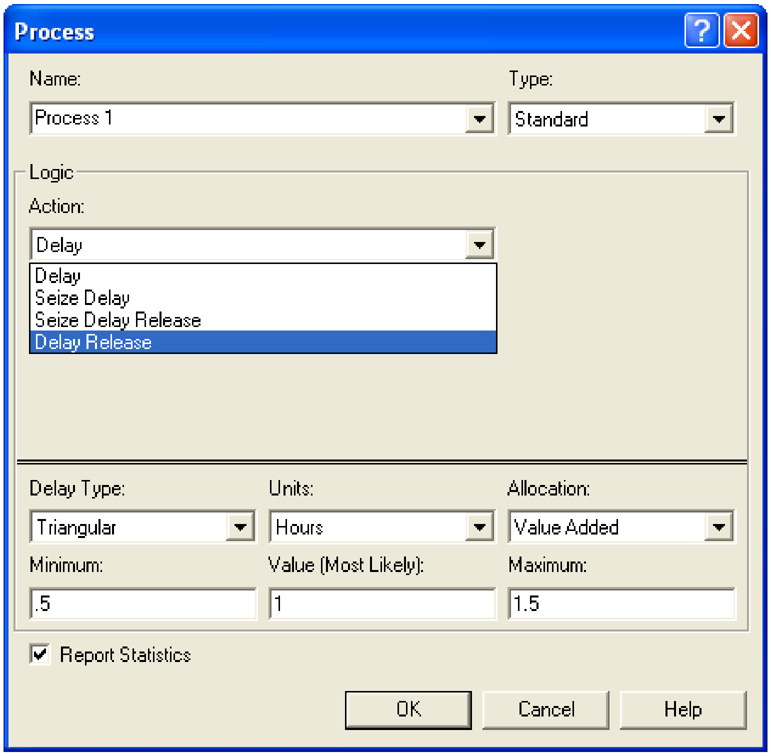

Figure 21. The GUI associated with an Arena Process Module.

The first Entity type explained is the ship type, to include OCS, T-AKE, and CS Entities. All ships entering the system attempt to *Seize Kilo*. If Kilo is unavailable, then the ship attempts to *Seize Buoy 702*. Any ship that enters the system and is denied either of these processes is held in the *Seize Buoy 702* Queue. If the ship is not able to *Seize Kilo*, but is able to *Seize Buoy 702*, then its next process is to *Seize Kilo from Buoy* when Kilo becomes idle. From this point on in the model, the processes are dependent on the Entity Type.

OCSs are held at Kilo until completely unloaded and then perform the *OCS Release Kilo Berth* process. This action releases the *Kilo Berth* resource and moves the OCS on to exit the system.

T-AKEs are held at Kilo until completely loaded and then perform the *TAKE Release Kilo* process. This action releases the *Kilo Berth* resource and moves the T-AKE on to exit the system.

CSs simply perform the Basic Process of delay and release at Kilo. *The CS Delay and Release Kilo* process uses an Expression to account for the delay of the Kilo Berth resource. This delay is a random distribution that was determined from historical data provided by the NEW Reports (Rivera, 2008). The historical data from the NEW Report was processed using the Input Analyzer tool in Arena. This tool provides the user with the ability to fit distributions quickly to the given input data. By accumulating the length of stay for CSs from 2003 through 2008, the data fits to a Uniform distribution, UNIF (4.01, 7) days. This action completes the process when it releases the *Kilo Berth* resource and moves the CS on to exit the system.

The next entity type explained is the Container. The first thing a Container must do is to seize a crane for movement off the OCS. The *Crane Moves Container from Ship to Pier* is a Basic Process that uses a Seize Delay action to perform container offloading. This action requires both a crane and a staging space at different lengths of usage time. The delay time for the crane in this action is an assumed random distribution that was calculated by converting the daily offload rates found in the CNA Report CRM D0017313.A1 (Goode & Smith, 2007), to an hourly rate per container, based on the range of containers offloaded in a day. The resulting calculated range is used in a Uniform distribution, UNIF (0.00735, 0.01225) hours, for lack of better data on high-volume offload rates.

Containers then *Release Pierside Staging Space For Ord Annex Container* or *Release Pierside Staging Space* when their appropriate destination is determined. From this point, the Container performs actions appropriate to their location. Containers that are unstuffed at the Ordnance Annex perform the action, *Ordnance Inspection at Ordnance Annex,* a standard Seize Delay Release action. One Ordnance Inspector per container is seized for the inspection and inventory during unstuffing. The delay in this action is assumed to be a Uniform distribution, whose range is based on historical unstuffing delays from the CNA Report CRM D0017313.A1 (Goode & Smith, 2007). The resulting calculated range is used in a Uniform distribution, UNIF (0.13333, 0.16667) hours, for lack of better data on high-volume offload rates.

Containers that are unstuffed at Kilo perform the action *Ordnance Inspection at Kilo*, a standard Seize Delay Release action. Seize and delay actions are assumed to the same as those for *Ordnance Inspection at Ordnance Annex* because it is the same process carried out at a different location.

The last entity type explained is Pallets. Pallets major process is the *Load Pallets to TAKE* process. This is a standard Seize Delay Release action where a pallet seizes an Ordnance Forklift and is loaded to the T-AKE with a delay of UNIF (2, 5) minutes. The Uniform distribution was based on the load times from the CNA Report CRM D0017313.A1 (Goode & Smith, 2007).

The processes described above do not include the entirety of processes in the system. All other processes can be found in Appendix A, Component and Module Specification for Modeling Ordnance Movements into the Asian Pacific Theater.

E. PRIMARY TRANSPORTERS

The primary transporters in the model are Container Capable Forklifts, Container Trucks, and Pallet Transport Trucks. This section provides a description of each of these transporter types.

There are two *Container Capable Forklift* free-path transporters in the model. These forklifts are top-handling (25 ton) container forklifts and assigned a velocity of 26,400 feet per hour. Since Arena does not allow for fractional velocities, the velocity of the *Container Capable Forklift* had to be converted to feet per hour. This value equates to five miles per hour, a reasonable estimate for an average velocity of *Container Capable Forklifts*. Figure 22 is a picture of the two currently available *Container Capable Forklifts* located on Guam.

Figure 22. Container Capable Forklifts (From: MSDDC, 2008).

There are eight *Container Truck* free-path transporters in the model (Goode & Smith, 2007). The *Container Truck* has an average velocity of 12 miles per hour. This value is based on the travel times calculated in the MSDDC Guam Ammunition Distribution Study (MSDDC, 2008).

There are 12 *Pallet Transport Truck* free-path transporters in the model (Goode & Smith, 2007). The *Pallet Transport Truck* has an average velocity of 12 miles per hour. This value is also based on the travel times calculated in the MSDDC Guam Ammunition Distribution Study (MSDDC, 2008).

F. VARIABLES OF INTEREST

This section describes the simulation parameters, or factors, that were chosen for the experiment. Factors are defined by the decision maker's ability to control them. A factor that is controllable by the decision maker in the real world is considered a decision factor. Uncontrollable factors are those beyond the decision maker's control, e.g., weather delays, ship repair requiring in port periods, or competing requirements. These uncontrollable factors are often referred to as noise factors. In this thesis, the factors that are controlled by the Navy are considered controllable factors, to include arrival cycles, supply and demand quantities, and processing policies. The noise factors in this thesis are factors such as the arrival of CSs and AF ordnance requirements. Table 6 provides the variable simulation parameters, for both decision and noise factors, and their associated ranges, used in the experimental designs.

Table 6. The Decision Factors and Noise Factors.

Factors	Range		Explanation
	Low	High	
v_OCS_Arr_Cycle	9	13	This cycle is directly related to v_TAKE_Arr_Cycle. The estimated replenishment cycle of the T-AKE based on operational demand requires an OCS approximately every eleven days. The range selected allow for minor variances in the arrival policy while maintaining sufficient supply of ordnance into the system.
v_TAKE_Arr_Cycle	10	20	This cycle is defined by the estimated ordnance sustainment requirements of a Marine Expeditionary Brigade (MEB) ashore. The range selected allows for an increase or decrease in arrival policy based on demand.
v_CS_Arr_Time*	23	60	This is the mean interarrival time for CS arrivals based on an exponential distribution. The range selected starts at the current level and explores the possibilities involved with a policy that limits CS entry into the system.
v_Cont_per_OCS	200	300	This is the number of containers offloaded from an OCS. The range explores changes in the current offload amount of approximately 255 containers. This range decision is possible because OCSs carry multiple loads (in reality) and can accommodate offloading more or less than currently prescribed.
v_percent_Navy_Cont*	0.7	0.9999	This is the direct competition for ordnance. The range defines a reduction in 100 percent ordnance supply by up to as much as 30 percent. The range is estimated on reasonable requirements during the contingency.
v_percent_unstuffed_pier	0.4	0.9999	This range represents the possibilities of the policy that defines where unstuffing occurs. Previous studies have suggested a change from 100 percent pierside unstuffing may increase throughput. The range was selected to exceed a a change by 50 percent to explore the policy possibilities.
Ordnance Inspector	18	27	This resource capacity range is for the number of qualified ordnance inspectors. The range selected represents the current to a 50 percent increase in personnel.

The * indicates the competing requirements/noise factors.

1. Controllable Factors

The following factors were chosen to explore the effect of competing requirements on the ordnance operations on Guam under a variety of possible support aspects.

a. Ordnance Container Ship Arrival Cycle (v_OCS_Arr_Cycle)

This is defined as the arrival cycle for OCSs to Guam. This cycle time is directly related to *v_TAKE_Arr_Cycle* and represents the supply required for combatant demand. Since the OCS carries more ordnance than is removed at one time, this model represents this by utilizing a rate proportionally higher to indicate the OCS delivering a partial load, going out to sea to loiter, and then returning to deliver another load. The estimated replenishment cycle of the T-AKE, based on operational demand, requires an

OCS arrival approximately every 11 days. The range of 9 to 13 allows for minor variances in the arrival policy, while maintaining sufficient supply of ordnance into the system.

b. T-AKE Arrival Cycle (v_TAKE_Arr_Cycle)

This cycle time is defined by the estimated ordnance sustainment requirement of an MEB ashore, which is every 16 days. The range of 10 to 20 allows for an increase or decrease in arrival policy, based on demand or available assets. Combined with other factors, the range may provide insights into how this policy affects throughput.

c. Number of Containers Offloaded per OCS Inport Period (v_Cont_per_OCS)

This is the number of containers offloaded from an OCS. The range explores changes in the current offload amount of approximately 255 containers. This range of 200 to 300 is possible because, in reality, OCSs carry thousands of containers and can accommodate offloading more or less than the 255 containers currently prescribed depending on the policy of ordnance operations.

d. Percent Unstuffed Pierside (v_percent_unstuffed_pier)

This is the policy that determines where containers are unstuffed. This range represents the possibilities of changes in this policy. Previous studies have suggested that a change from 100% pierside unstuffing may increase throughput. The range was selected to exceed a change by 50% to explore the policy possibilities. During noncontingency times, pierside unstuffing cannot be determined to be the optimal policy, although it is the one most often used.

e. Ordnance Inspector Capacity

This is the number of qualified ordnance inspectors available to inventory and inspect pallets of ordnance during the unstuffing process. During a contingency, this number may be increased from the current availability to meet the operational tempo.

The ease of changing this number in reality, and the ordnance inspector's significant role in ordnance operations, makes this a good factor to explore. The range selected represents the current availability to a 50% increase in personnel.

f. Unstuffing Space Capacity

This resource capacity range is for the number of actual physically available spaces to unstuff ordnance. Previous studies have suggested that an increase in this resource availability would increase ordnance operational efficiency. Selection of this decision factor explores those suggestions in an effort to provide quantitative analysis of the improved efficiency. This range represents the current amount of space up to a 25% increase. Amounts larger than the selected high level would require an infeasible amount of physical space.

g. Ordnance Forklifts

This resource capacity range is for the number of available ordnance forklifts available for the loading of ordnance to T-AKEs. The range represents a 50% increase in the resource capacity from the current level. This explores the possible impact of a relatively inexpensive increase in resources on ordnance operations on Guam.

2. Uncontrollable Factors

The noise factors, generally comprised of the competitive requirements, are used to ensure that conclusions drawn from this thesis are reflective of the broad exploration of competing requirement effects. These are the factors that the thesis sponsor, OPNAV N421, wants explored in this thesis.

a. Competing Ship Arrival Time (v_CS_Arr_Time)

This is the mean interarrival time for CSs. This random interarrival time required a suitable distribution. Real-world data, gathered by NMC Guam for Kilo Wharf occupancy during a five-year period from 2003 to 2008, provides the distribution for *v_CS_Arr_Time*. The distribution of *v_CS_Arr_Time* is shown in Figure 23 and is defined by the expression, *v_CS_Arr_Time* = -0.001 + EXPO (23.7), where the value

23.7 is the average interarrival time for competing ships. The range selected starts at the current level and explores the possibilities involved, with a policy that limits CS entry into the system.

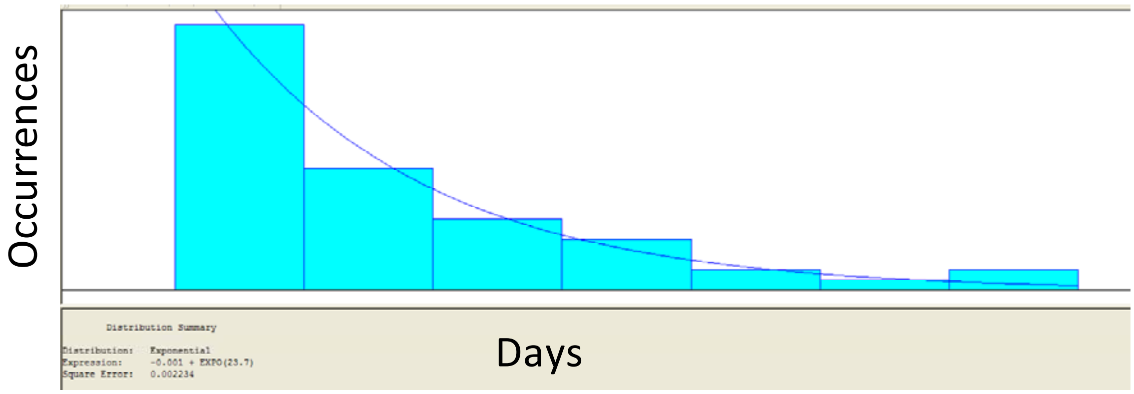

Figure 23. Arena Input Analyzer output for CS Interarrival Time.

b. *Percent of Containers for United States Navy (v_percent_Navy_Cont)*

This factor defines the competing requirement for ordnance by the Air Force. A larger competing requirement decreases *v_percent_Navy_Cont*. Although the forces would be operating in a joint effort during a military contingency, the Navy does not have control of AF requirements for ordnance. The range defines a reduction in 100% ordnance supply by up to as much as 30%. The range is estimated based on reasonable requirements during the contingency.

3. Other Variables of Interest

a. *Universal Stream Indicator (v_Univ_Stream)*

The universal stream indicator is a variable that is attached to every expression in the model that uses the random number seed. By attaching the universal stream indicator, the model then produces a set of replications using the same random number stream. This is critical to using the Process Analyzer in Arena in conjunction with DOE. When the set of replication (a run) is completed, the model moves to a new set of input parameters. The universal stream indicator applies a new random number stream to the subsequent run, thus producing runs that are independent of each other. This random-number-stream allocation ensures independence not only with scenarios, but also across them as well.

b. Initial Inventory (v_Initial_Inventory)

In this model, the initial inventory variable is used for two purposes. The first is to build the initial starting condition inventory. This developed into its second purpose through the debugging process and second scenario of the experiment. Once competition is added into the system, a much higher initial inventory is required for the model to successfully complete the minimum simulation requirement of one year of operating time. Therefore, the second purpose became a test for the starting condition feasibility. This secondary purpose is further discussed in Section C of Chapter V.

G. THE EXPERIMENT

This thesis uses five scenario sets to conduct the experiment. The first is a baseline scenario that uses a combination of the ordnance operations process observed in reality, and input parameters from the previous studies in the simulation model, in an effort to establish a verifiable baseline. Validation indicates that the model used in this thesis models the process flow as a close as possible to reality based on the previous studies of CNA and MSDDC. This scenario will act as the control scenario.

The second scenario is the initial introduction to competing requirements to the system. The third scenario is another baseline scenario in which the model represents a physical change to the system. The fourth scenario set is similar to the second in that it introduces competing requirements to the new system baseline in the third scenario. The fifth scenario set is the experimentation set, where the landscape of possible outcomes is explored. Orthagonal Latin Hypercubes (OLH) and the Nearly Orthogonal Hypercubes (NOLH) are the primary method of exploring the factor space for insights in this thesis (Cioppa, 2002). Both methods of DOE were used, based on the number of input parameters required in the scenario. The OLH and NOLH are quickly developed by using the automated versions of the OLH and NOLH (Sanchez, 2005) found on the SEED Center Website, http://harvest.nps.edu.

The purpose of this thesis is not to predict outcomes, but rather, to provide insights into the effect of new factors introduced to the system (competing requirements) and the variability of existing factors. Therefore, the response data in each experimental scenario set is twofold. The first response measures T-AKE service level by calculating the ratio of T-AKEs that are served by the system, to those who enter the system. By using an unprioritized queue in the model, this information is captured easily. The second response is the total number of pallets that are processed out. Although these two measures appear corrolated quite closely, it is important to measure the service level to the combatants in this manner. For all intents and purposes, the combatants do not care if the ordnance operations cannot service 100% of T-AKEs that enter the system, as much as they care about receiving a sufficient amount of ordnance; in the case of this thesis, pallets of ordnance.

1. Scenario Set 1 – The Baseline Model

The baseline model is a representation of the system as it exists at present. The two primary competing requirement factors are built into the baseline, but their input values are set to model no competition. CSs are not introduced to the system and the Navy receives 100% of all containers that arrive on an OCS. This setting is a direct comparison to the previous study done by CNA. The input parameters in the baseline are set to constant values and the variability of the model response after 100 replications is caused by the inherent variability some of the processes possess. Table 7 displays the input parameters for the baseline. These parameters mirror current operating policy, physical reality, and the input parameters of previous studies.

Table 7. Input Parameters For Scenario Set 1 – Baseline.

v_OCS_Arr_Cycle	v_TAKE_Arr_Cycle	v_CS_Arr_Rate (λ)	v_Cont_per_OCS	v_percent_Navy_Cont	v_percent_unstuffed_pier	Ordnance Inspectors	Unstuffing Space	v_Univ_Stream
11	16	0	255	0.9999	0.9999	18	120	118

The responses for this model are the standard for all scenarios run in this thesis: T-AKE service level and pallet throughput. The baseline model is also the model used to debug the simulation before proceeding with further experimentation.

2. Scenario Set 2 – Addition of Competing Requirements

Scenario Set 2 is the first experiment conducted on the system. This scenario examines the effect of adding the competing requirements to the system. Differences from the baseline model include using the CS interarrival rate determined by historical data and the possibility for the Navy to receive less than 100% of the ordnance entering the system. The effect of competing scenarios is seen in comparison to the baseline scenario. Table 8 displays the input parameters for Scenario Set 2.

Table 8. Input Parameters for Scenario Set 2 – Competing Requirements.

v_OCS_Arr_Cycle	v_TAKE_Arr_Cycle	v_CS_Arr_Rate (λ)	v_Cont_per_OCS	v_percent_Navy_Cont	v_percent_unstuffed_pie	Ordnance Inspectors	Unstuffing Space	v_Univ_Stream
10	20	25	238	0.78	0.96	25	143	101
9	13	23	256	0.7	0.59	19	145	102
10	14	24	225	0.89	0.89	24	160	103
10	16	24	300	0.87	0.48	17	150	104
12	19	28	213	0.79	0.4	16	153	105
13	13	30	281	0.72	0.85	24	155	106
12	12	27	231	0.96	0.66	20	158	107
11	19	27	294	0.94	0.78	22	148	108
11	15	27	250	0.85	0.7	21	140	109
12	10	28	263	0.93	0.44	17	138	110
13	18	30	244	0.9999	0.81	23	135	111
13	16	29	275	0.81	0.51	18	120	112
12	14	29	200	0.83	0.93	25	130	113
10	11	25	288	0.91	0.9999	26	128	114
9	17	23	219	0.98	0.55	19	125	115
11	18	26	269	0.74	0.74	22	123	116
11	11	26	206	0.76	0.63	20	133	117

The responses for this model are used to quantify the effect of competing requirements and for analysis into which of the input parameters have a significant effect on the system.

3. Scenario Set 3 – Simulating Completion of the New Magazine on Orote Baseline

Scenario Set 3 is the baseline for an experiment to explore the effect of the NAVFACMARIANAS Project, P-425, on the system. This project is building a new magazine located on the Orote Peninsula in an effort to increase safety and reduce the amount of transit time to and from the Ordnance Annex. This scenario uses the original baseline model scenario setup, with the exception of an adjusted distance set to account for the new magazine. The model assumption generously gives the new magazine the same capacity as the Ordnance Annex. By doing this, the original model is easily altered to reflect a closer facility, changing the distance from Kilo Wharf to the Annex from seven miles down to one mile. The remaining input parameters remain the same as those seen in Table 7 - Input Parameters for Scenario Set 1 – Baseline.

The responses in this model are used in comparison to the original baseline and to the next Scenario Set. These comparisons show both the effect of the new magazine to the existing system and the impact of competing requirements in the new system.

4. Scenario Set 4 – Simulating Completion of New Magazine on Orote

Scenario Set 4 is the experiment that introduces the competing requirements to the new magazine baseline set up in Scenario Set 3. The purpose of this scenario is to explore the impact of competing requirements on the system with the new magazine. The same input parameters used in Scenario Set 2 are used to evaluate the system in this experiment. This provides a method for not only comparing the responses of this scenario to its baseline scenario, but also for comparison to Scenario Set 2.

5. Scenario Set 5 – Exploratory Set

Scenario Set 5 is the experiment that uses all the input parameters listed in Table 6 to explore a broad landscape of possibilites. The purpose of this experiment to evaluate which input parameter has a significant effect on the response. The nine input parameters used in this experiment all relate to viable changes that can be implemented in the system. Insights from the analysis of this experiment provide a basis for recommendations regarding changes to the system. These changes can be represented in either policy changes or resource allotments in the system. Table 9 represents the nine input parameters and the universal stream indicator variable.

Table 9. Input Parameters by Scenario for Scenario Set 5.

	v_OCS_Arr_Cycle	v_TAKE_Arr_Cycle	v_CS_Arr_Rate (λ)	v_Cont_per_OCS	v_percent_Navy_Cont	v_percent_unstuffed_pier	Ordnance Inspectors	Unstuffing Space	Ordnance Forklifts	v_Univ_Stream
low level	9	10	23	200	0.7	0.4	18	120	8	--
high level	13	20	60	300	0.9999	0.9999	27	160	12	--
decimals	0	0	0	0	4	4	0	0	0	
	13	11	39	219	0.9624	0.7749	22	160	11	101
	13	20	28	238	0.8406	0.5125	21	156	11	102
	13	14	57	216	0.7094	0.7562	18	133	11	103
	11	19	60	241	0.9812	0.4937	19	138	11	104
	13	10	40	222	0.9062	0.8312	23	123	10	105
	13	19	35	228	0.8312	0.5312	26	121	9	106
	12	15	59	225	0.7	0.7937	26	155	10	107
	11	17	58	234	0.9718	0.55	27	141	9	108
	12	13	31	253	0.9156	0.5875	20	144	8	109
	12	17	33	269	0.7656	0.7187	21	154	8	110
	12	12	51	297	0.8031	0.4375	19	135	9	111
	12	17	47	294	0.9249	0.9812	22	129	10	112
	11	12	30	256	0.8781	0.475	25	134	12	113
	12	16	37	288	0.7469	0.7374	24	130	12	114
	12	12	54	291	0.8125	0.4	25	149	11	115
	12	16	45	300	0.9437	0.9437	24	153	10	116
	11	15	42	250	0.85	0.7	23	140	10	117
	9	19	44	281	0.7375	0.625	23	120	9	118
	9	10	55	263	0.8593	0.8874	24	124	9	119
	10	16	26	284	0.9905	0.6437	27	148	9	120
	11	11	23	259	0.7187	0.9062	26	143	9	121
	9	20	43	278	0.7937	0.5687	22	158	10	122
	9	11	48	272	0.8687	0.8687	19	159	11	123
	10	15	24	275	0.9999	0.6062	19	125	11	124
	11	13	25	266	0.7281	0.8499	18	139	11	125
	10	18	52	247	0.7843	0.8124	25	136	12	126
	10	13	50	231	0.9343	0.6812	24	126	12	127
	10	18	32	203	0.8968	0.9624	26	145	12	128
	10	13	36	206	0.775	0.4187	23	151	10	129
	11	18	53	244	0.8218	0.9249	20	146	8	130
	10	14	46	213	0.953	0.6625	21	150	8	131
	11	18	29	209	0.8874	0.9999	20	131	9	132
	10	14	38	200	0.7562	0.4562	21	128	10	133

A secondary purpose of this experiment is to develop a set of observations that can be used for future research. By providing the decision maker with information about which factors have significance in the model, future research can be used to investigate these factors even further.

6. Simulation Runs and Replications

Each of the design points in the Scenario Sets was replicated 100 times, with a total run time of approximately 8 to 10 minutes per design point. This provides adequate precision to resolve differences in statistically significant ways, while at the same time proving workable in terms of computing time. The Process Analyzer in Arena allows for the selection of all design points in an experiment and running them consecutively. The universal stream indicator is used as an input into the Process Analyzer. This applies a new random number stream to the subsequent run, thus producing runs that are independent of each other. This random-number-stream allocation ensures independence not only with scenarios, but also across them as well. This simplified the experimentation by allowing the analyst to start an experiment in the morning and return in the afternoon to a completed run of the experiment.

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IV. DATA ANALYSIS

The experimental scenario sets described in Chapter III provide an opportunity to generate a significant amount of data for analysis. In this chapter, the focus is on discovering insights into the movement of ordnance into the Asian Pacific Theater. In an effort to address the thesis questions presented in Chapter I, the analysis is centered on the MOEs of interest, T-AKE Service Level (SL), the ratio of T-AKEs serviced by the system, and Pallet Throughput (Pallets Out).

This chapter begins with a brief description of the data collection and post-processing methods. Following a detailed scenario-by-scenario analysis of the data, the thesis presents insights and conclusions drawn from the analysis.

A. DATA COLLECTION AND POST PROCESSING

Data collection, using the Process Analyzer in Arena, is a very simple process. The Process Analyzer gathers response data, defined by the analyst as the statistical averages of replications in each run. Although useful for looking at system performance averages, the run average data does not allow analysts to look at the landscape of possible outcomes in a refined manner. To do this, the individual output from each replication is required. In order to gather the response data from individual replications, the response data is an intermediate step required during data collection. Response data from individual replications are passed to an Excel spreadsheet via the *Output to a spreadsheet* segment in the model. At the time that a replication reaches the finishing time for the simulation, *tfin*, the model creates an entity that directs the output of statistics gathered during the simulation to write out to a specified file. Figure 24 is the *Output to a spreadsheet* segment, and the associated GUI that is used to identify which statistics are sent to the output file.

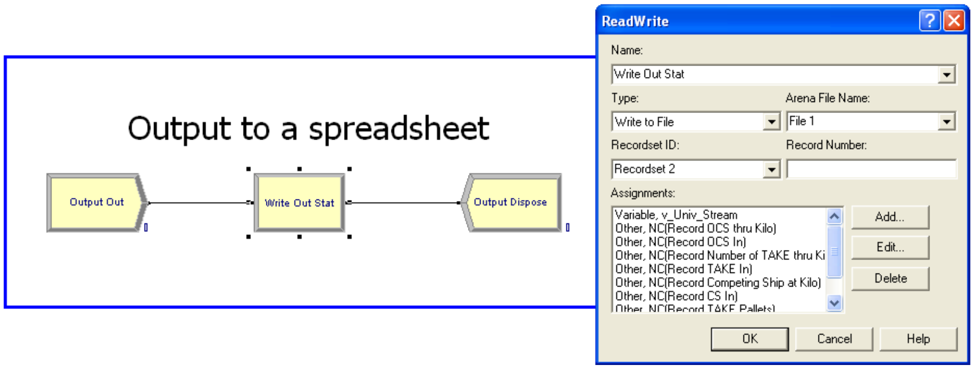


Figure 24. The Models Output Segment.

The flexibility of this feature in the model allows the analyst to define many different statistics gathered by Arena, or those defined in the model by the analyst.

Once the output data are written to the Excel spreadsheet, they are ready for post processing. In this thesis, post processing primarily consists of merging the columns of input data into the output file and conversion of the output data into the T-AKE SL. The MOE, T-AKE SL, is calculated by simply dividing the number of T-AKEs that enter the system by the number of T-AKEs that leave the system. This ratio provides an MOE bounded by 0 and 1. This ratio is presented as a percentage, where bigger values equal higher service levels. Therefore, a perfectly running system will not have anyone in queue and have a SL of 1. The Pallets Out MOE is simply a tally statistic that is gathered within the model and is automatically reported as output response data. Once the output response data is processed in Excel, it is imported into JMP Statistical Discovery Software version 7.0, which is the primary tool used for the remaining post processing and analysis.

B. INSIGHTS INTO RESEARCH QUESTIONS

Recall from Chapter I the two general questions about the movement of ordnance into the Asian Pacific Theater that this thesis sets out to answer.

- What is the impact on competing requirements to the movement of ordnance into the Asian Pacific Theater?
- What, if any, are the critical factors related to providing maximum T-AKE SLs and Ordnance Pallet throughput?

These questions are directly addressed through data analysis in the following section.

1. MOE Correlation Analysis

The first step in the analysis is to validate the need to analyze both MOEs. The initial hypothesis is that T-AKE SL and Pallets Out are correlated. The Correlations Multivariate option in JMP gives the Correlations table, which is a matrix of correlation coefficients that summarizes the strength of the linear relationships between each pair of response (Y) variables. This correlation matrix only uses the observations that have nonmissing values for all variables in the analysis (SAS Institute Inc., 2007). Figure 25 is the correlation matrix and scatterplot for the chosen MOEs in Scenario Sets 1 and 2.

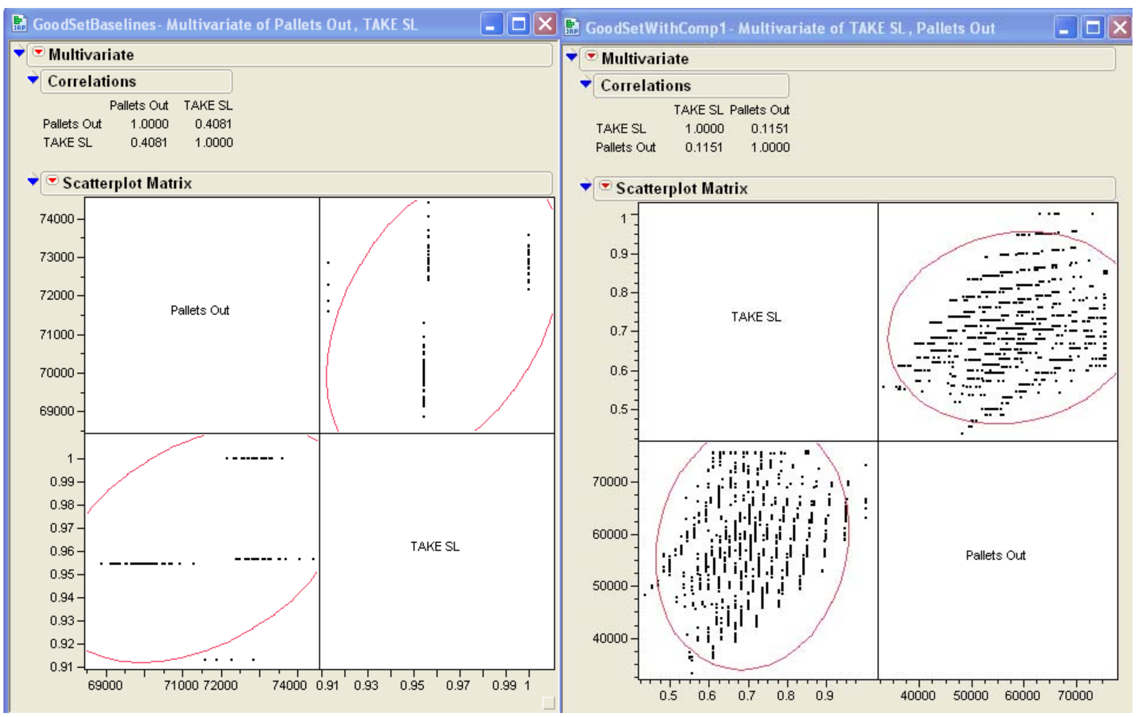


Figure 25. Correlation and Scatterplot Matrix for MOEs.

As observed in Figure 25, the MOEs are not strongly correlated. An explanation for the lack of correlation is that T-AKE SL is a ratio of T-AKEs that enter the system to those that leave the system. This implies that the closer the cycle of T-AKEs, the higher the likelihood of congestion with other vessels at Kilo Wharf. Therefore, T-AKE SL is more likely to be correlated with T-AKE arrival frequency. Figure 26 shows a stronger correlation between T-AKE SL and T-AKE arrival frequency. It also shows that Pallets Out has a strong negative correlation (–0.74) to T-AKE arrival frequency. This is a sensible result because a lower T-AKE arrival frequency means less overall opportunity for successful services. Thus, fewer pallets are drawn from the system, since Pallets Out is a function of the T-AKE demand.

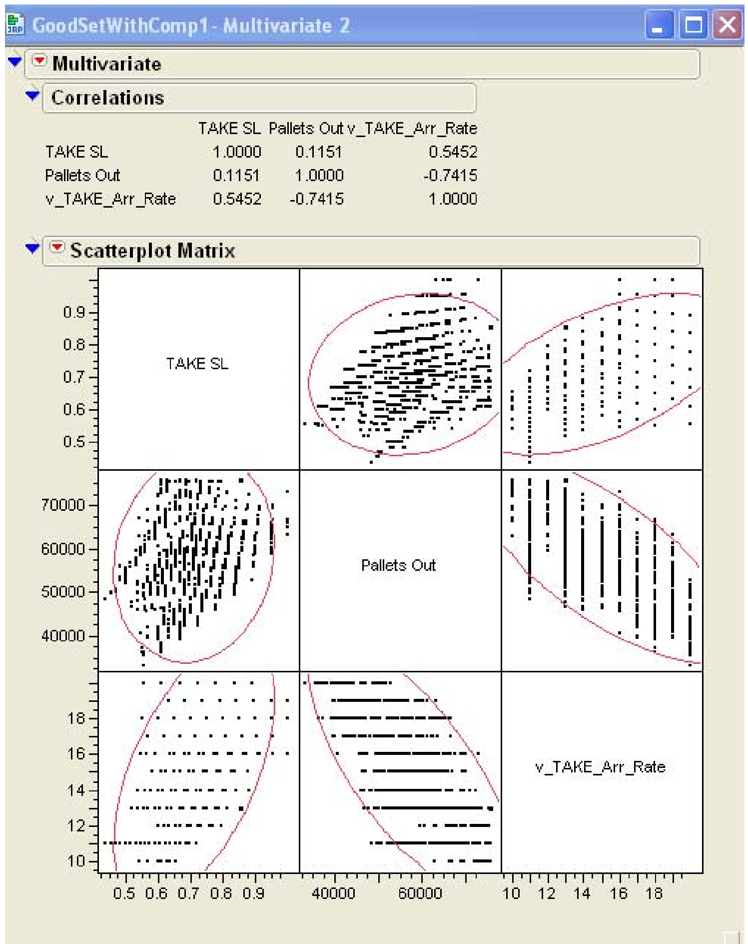


Figure 26. Correlation and Scatterplot Matrix for MOEs and T-AKE Arrival Frequency.

With no strong correlation between the MOEs, the analysis in this section is focused on both MOEs as separate measures of the impact of competing requirements and parameter variability.

2. Analysis of Scenario Set 1 - The Baseline Model

Anchoring the experimental design of this thesis is a reliable baseline. This section analyzes the baseline data and, by using the input parameters defined in the CNA and MSDDC studies, determines if the baseline is feasible. Figure 27 shows the distributions of the Scenario Set 1 MOEs.

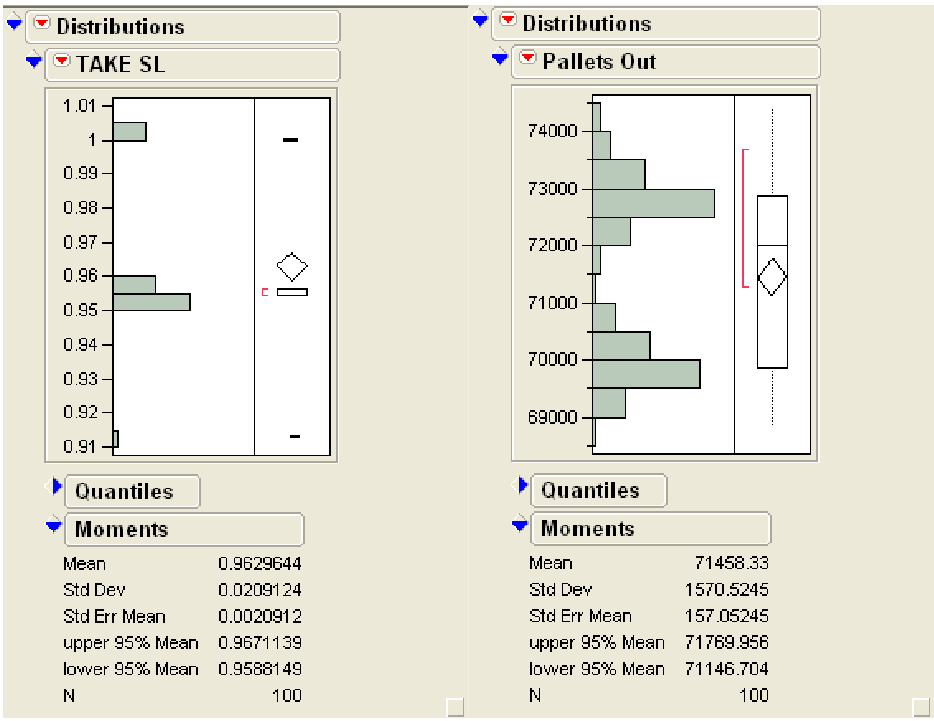


Figure 27. Scenario Set 1 – The Baseline Model MOE Distributions.

The baseline scenario produced a mean T-AKE SL of 96.30%, with a 95% confidence interval of (95.88, 96.71). It also produced a mean Pallets Out value of 71458 pallets, with a 95% confidence interval of (71147, 71770). By using the input parameters recommended by the previous studies mentioned, the baseline is feasible and operates at a high T-AKE SL and produces a throughput of pallets sufficient to meet the minimum requirement for T-AKEs supporting an MEB ashore.

3. Analysis of Scenario Set 2 – Addition of Competing Requirements

Upon the addition of competing requirements to the system, quantitative measurement of the impact on the system is measured. Comparing this scenario against the baseline scenario shows the immediate quantitative results of competing requirements. Figure 28 shows the comparison of the distributions of Scenario Sets 1 and 2 T-AKE SL.

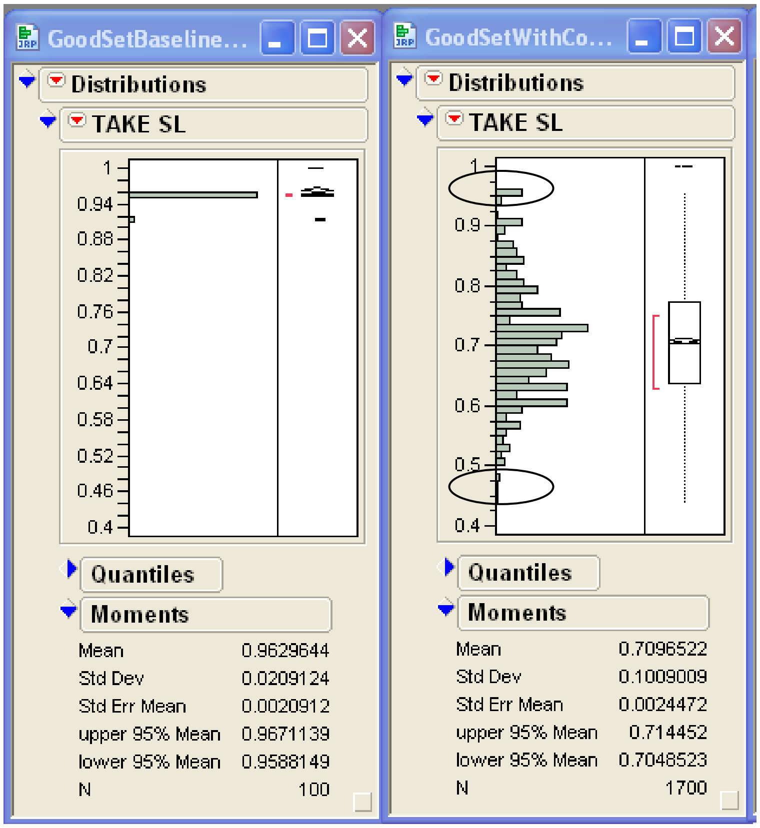


Figure 28. Scenario Sets 1 and 2 T-AKE SL Distribution Comparisons.

Considering that there is no overlap of the T-AKE SL confidence intervals between Scenarios 1 and 2, the impact of competing requirements on the system is significant and not attributable to the model variance. The Competing Requirements scenario produced a mean T-AKE SL of 70.97%, with a 95% confidence interval of (70.49, 71.45). When compared to the baseline, T-AKE SL sees an impact of 25.33% reduction in expected service level.

The specific design points within the scenario set that performed best and worst are indicated in Figure 28. For the design points that performed well, the only commonalities seen in the inputs are a higher number of *v_Cont_per_OCS* and higher percentages of *v_percent_Navy_Cont*. As for the poorest performing design point, in contrast to the better performers, it has lower values for both *v_Cont_per_OCS* and *v_percent_Navy_Cont*. This insight is analyzed further later in this section.

The Competing Requirements scenario produced a mean Pallets Out value of 579034 pallets, with a 95% confidence interval of (57437, 58370). Concurrently, the mean of pallet output is reduced by 13,554 pallets annually. As a percentage of reduction in pallet throughput, competing requirements reduce the system by approximately 18.97%. A comparison of Pallets Out is seen in Figure 29.

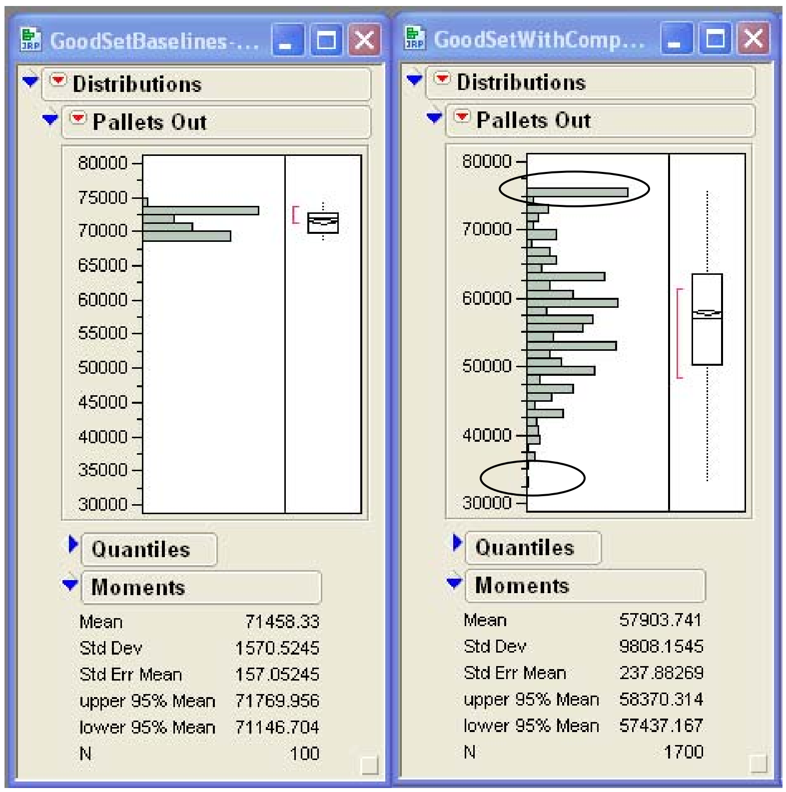


Figure 29. Scenario Sets 1 and 2 Pallets Out Distribution Comparisons.

The specific design points within the scenario set that performed best and worst are indicated in Figure 29. For the design points that performed well, the only commonalities seen in the inputs are a lower *v_TAKE_Arr_Cycle* and higher percentages of *v_percent_Navy_Cont*. As for the poorest performing design point, in contrast to the better performers, it has higher values for *v_TAKE_Arr_Cycle* and lower values for *v_percent_Navy_Cont*. This insight is analyzed further later in this section.

Looking at system performance in broader terms, Figure 30 shows the comparison of the annual mean values for the MOEs and their measurable differences.

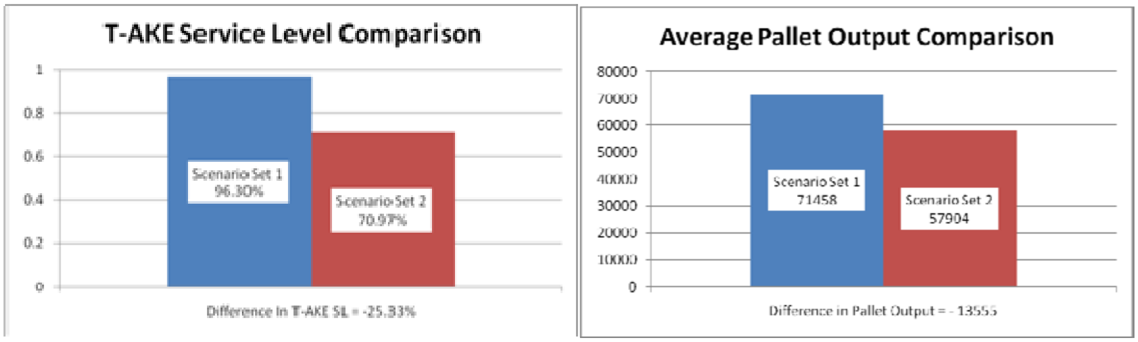


Figure 30. Scenarios 1 and 2 MOE Annual Average Value Comparisons.

By quantifying the significant effect of competing requirements on the system, the next step in analysis of this scenario is to explore the factors in the model that are contibutors to this effect. In order to identify these possible significant factors, both regression analysis and the nonparametric method of regression tree partitioning are used to see if any particular factors in the model are significant.

In the Step History table, a stepwise regression analysis of both Scenario Set 2 MOEs indicates the order in which the terms entered the model and shows the effect, as reflected by RSquare. The significant factors in the set are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_Cont_per_OCS*, and *v_percent_Navy_Cont*. Figure 31 is the JMP output for a stepwise regression analysis of Scenario Set 2.

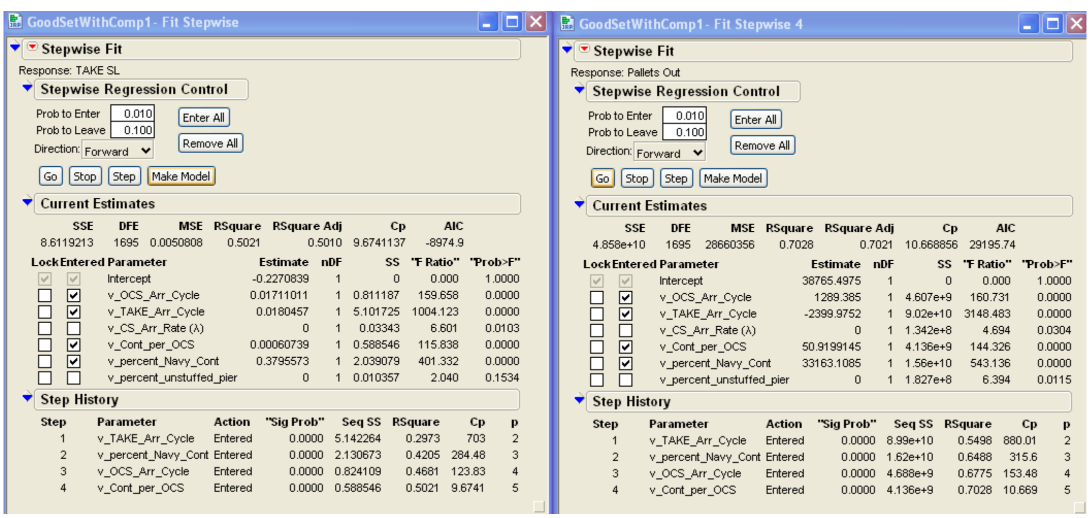


Figure 31. Stepwise Regression Analysis of Scenario Set 2.

Using this analysis, *v_TAKE_Arr_Cycle* is the largest contributing factor for both MOEs. In the case of T-AKE SL, for every additional day added to the *v_TAKE_Arr_Cycle* interval, the service level increases by approximately 2%. This result makes sense in that as the number of T-AKEs that enter the system goes down, the traffic intensity seen at Kilo Wharf decreases, and allows for fewer ships in the queue. Fewer ships in the queue translates into increased chances of reaching Kilo Wharf and completing service. In the case of Pallets Out, for every additional day added to the *v_TAKE_Arr_Cycle* interval, the number of Pallets Out decreases by approximately 2,400 pallets. This result also makes sense. As fewer T-AKEs enter the system, the opportunity for T-AKEs to load pallets also decreases.

The factor, *v_OCS_Arr_Cycle*, contributes to the T-AKE SL with the same logic as *v_TAKE_Arr_Cycle*. More OCSs equates to more chances of waiting in the queue and less chance of being served. However, when considering Pallets Out, *v_OCS_Arr_Cycle* has a reciprocal effect. As the arrivals of OCSs becomes more spread out, more T-AKEs are able to be served and therefore, Pallet Out increases.

Scenario Set 2 main effects regression analysis of both MOEs indicates by a Prob>|t| that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_Cont_per_OCS*, and *v_percent_Navy_Cont*. Prob>|t| is the probability of getting an even greater t-statistic (in absolute value), given the hypothesis that the parameter is zero. This is the two-tailed test against the alternatives in each direction. Probabilities less than 0.05 are often considered as significant evidence that the parameter is not zero (SAS Institute Inc., 2007). Figure 32 is the JMP output for a main effects regression analysis of Scenario Set 2.

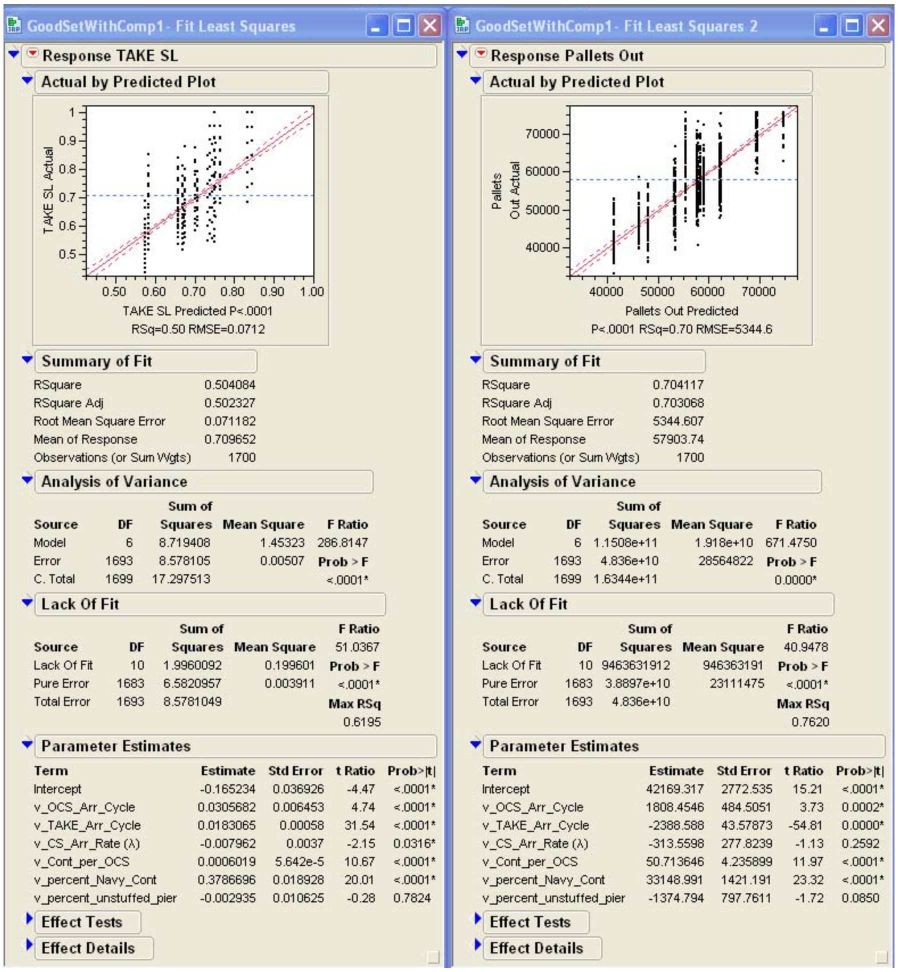


Figure 32. Regression Analysis of Scenario Set 2.

The results of the regression analysis direct the focus of the nonparametric analysis that follows. Before arbitrarily partitioning the data, a decision is required to determine the approriate number of partitions used in the analysis. Deciding the approriate number of partitions is accomplished by plotting the RSquare values by partition to find a point of diminishing returns. RSquare estimates the proportion of the variation in the response around the mean that can be attributed to terms in the model, rather than to error (SAS Institute Inc., 2007). An initial number of 10 partitions is used to evaluate the RSquare. Figure 33 shows the RSquare plot for Scenario Set 2 partitions and indicates where the diminishing returns are observed for further partitions.

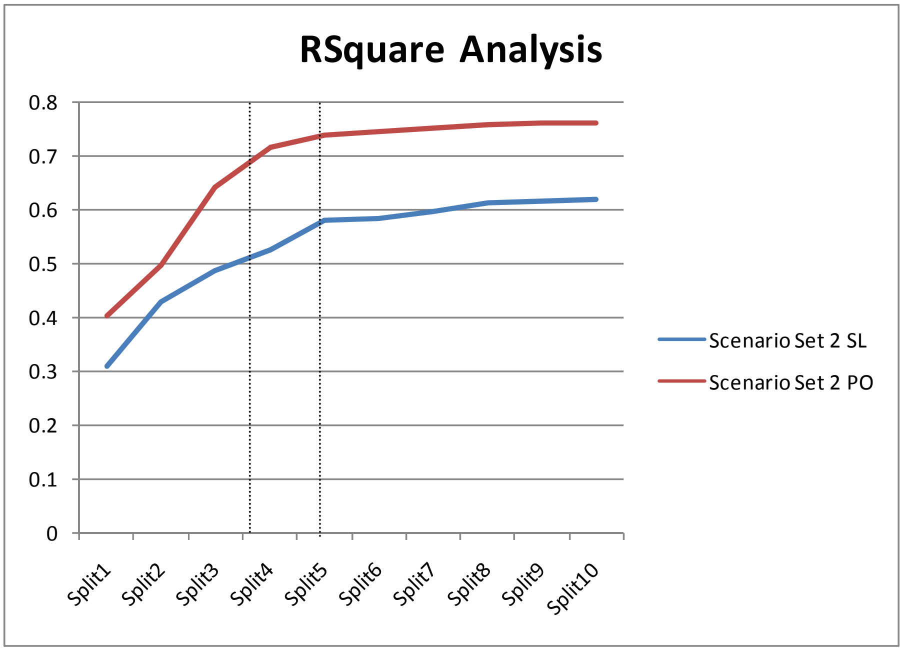
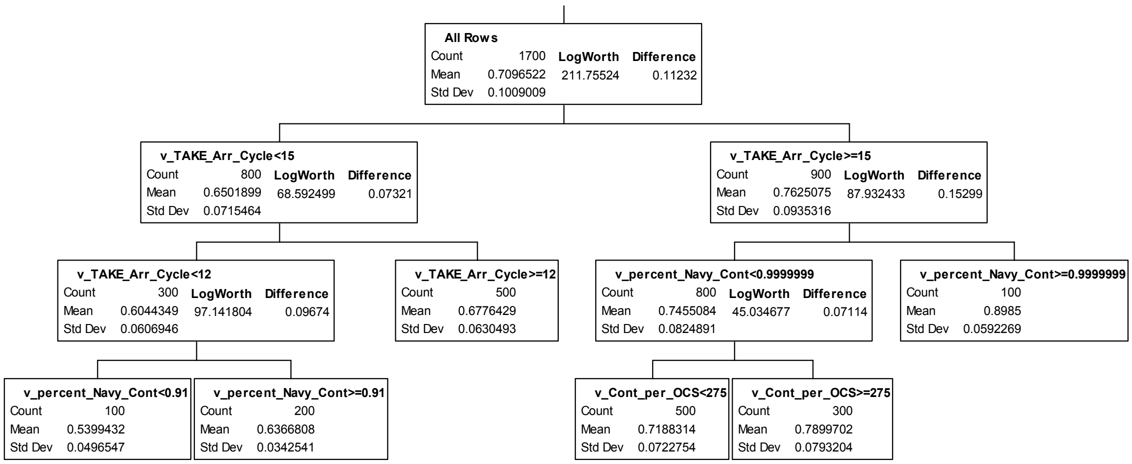


Figure 33. RSquare Plot for Scenario Set 2 Partitions.

By evaluating the 10 partitions, the bend in the curve for both MOEs occurs between the fourth and fifth split for each MOE. Using this information, each MOE is evaluated through the fifth partition. Using the regression analysis previously conducted, along with the partition trees, provides insights into how the significant factors involve themselves in the system under certain conditions.

The Partition platform in JMP 7.0 recursively partitions data according to a relationship between the X and Y values, creating a tree of partitions. It finds a set of cuts, or groupings, of X values that best predict a Y value. It does this by exhaustively searching all possible cuts or groupings. These splits (or partitions) of the data are done recursively, forming a tree of decision rules until the desired fit is reached (SAS Institute Inc., 2007). Figure 34 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	0	0
v_TAKE_Arr_Cycle	2	6.34781394
v_CS_Arr_Rate (λ)	0	0
v_Cont_per_OCS	1	0.94888709
v_percent_Navy_Cont	2	2.70444846
v_percent_unstuffed_pier	0	0
Total	5	10.0011495

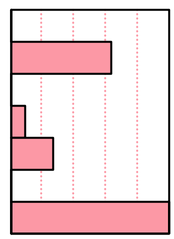
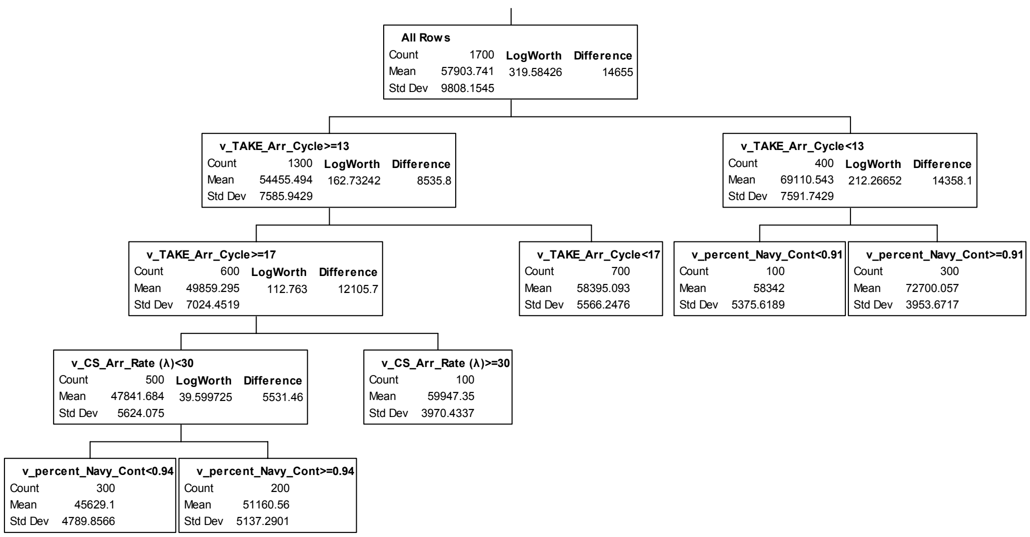


Figure 34. Partition and Column Contribution of T-AKE SL in Scenario 2.

The largest contributor through five partitioning splits is the decision factor, *v_TAKE_Arr_Cycle*. This is expected because a well-timed arrival rate for T-AKEs minimizes the number of T-AKEs that are held in queue. This results in maximizing the number of T-AKEs that are served, thus an increase in T-AKE SL. The only competing requirement shown as a critical factor is *v_percent_Navy_Cont*. The only factor indicated as having significance in the regression analysis, that does not appear in the first five partitions, is the factor *v_OCS_Arr_Cycle*.

The partition tree also provides insights into situational influences of the input parameters on the system. For example, the first split is on *v_TAKE_Arr_Cycle* greater than or equal to 16. Following the split to the right, the next influencing parameter is the competing requirement, *v_percent_Navy_Cont*. Therefore, in a situation in which the T-AKE cycle is greater than 16 days, the best policy for maximizing T-AKE SL is to have 100% Navy ordnance. If this is not possible, the mean T-AKE SL will be 74%. This type of “If-Then” analysis is useful to the decision maker when faced with situational decision making.

Again here, the largest contributor through five partitioning splits is the decision factor, *v_TAKE_Arr_Cycle*. As discussed in the the T-AKE SL analysis, this result is expected. An unexpected difference in the partition tree analysis from the regression analysis is the contribution of *v_CS_Arr_Time*. In this partition tree analysis, both competing requirement factors, *v_percent_Navy_Cont* and *v_CS_Arr_Time*, are shown as critical factors. However, just as in the analysis on the T-AKE SL partition, *v_percent_Navy_Cont* is a larger contributor in the Pallets Out partition. From examination of the tree in Figure 34, the number of Pallets Out is most affected when the competition for ordnance is greater than 9% in this Scenario Set. Figure 35 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	0	0
v_TAKE_Arr_Cycle	2	8.9234e+10
v_CS_Arr_Rate (λ)	1	1.2212e+10
v_Cont_per_OCS	0	0
v_percent_Navy_Cont	2	1.9133e+10
v_percent_unstuffed_pier	0	0
Total	5	1.2058e+11

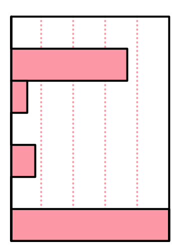


Figure 35. Partition and Column Contribution of Pallets Out in Scenario 2.

In summary, Scenario Set 2 quantifies the effect of including competing requirements to the system as a reduction in mean T-AKE SL by 25.33% and mean Pallets Out by 18.97%. Scenario Set 2 also indicates that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_Cont_per_OCS*, and *v_percent_Navy_Cont*. Of these, *v_TAKE_Arr_Cycle* appears as the strongest candidate of all inputs, and *v_percent_Navy_Cont* appears as the strongest candidate of the competing requirements to have the greatest effect on the system.

4. Analysis of Scenario Set 3 – Simulating New Magazine Baseline

Scenario Set 3 is similar to Scenario Set 1, with the exception of the distance to the primary ordnance storage facility. The expected results are an increase in both MOEs, as compared to the initial baseline of Scenario Set 1. Figure 36 shows the distributions of Scenario Set 1's and 3's MOEs.

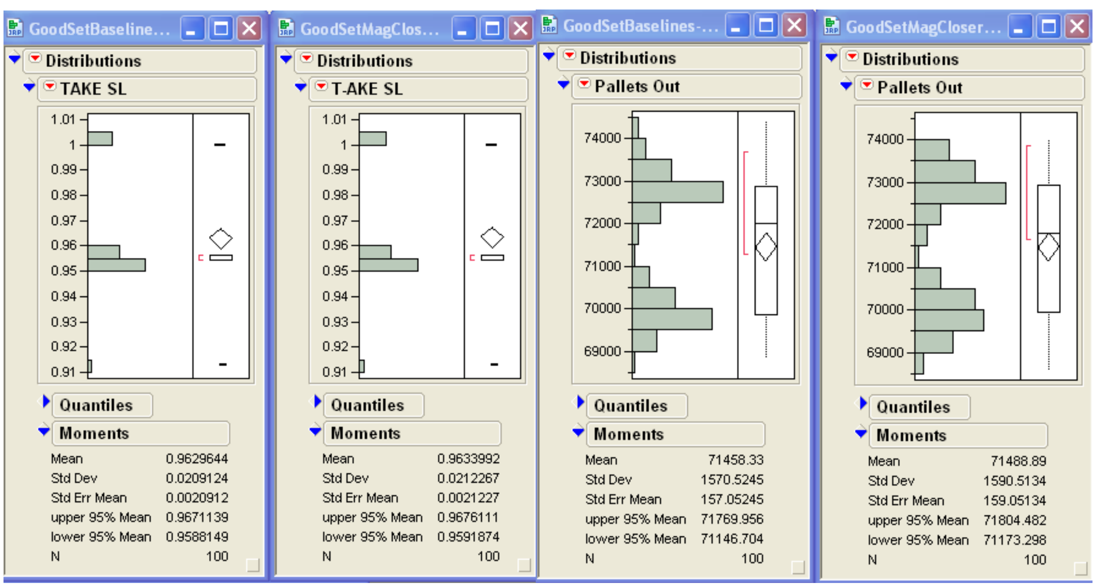


Figure 36. Scenario Sets 1 and 3 – Direct Comparisons of MOE Distributions.

The New Magazine Baseline scenario produced a mean T-AKE SL of 96.34%, with a 95% confidence interval of (95.92, 96.76). It also produced a mean Pallets Out value of 71488.89 pallets, with a 95% confidence interval of (71,173.30, 71,804.48). When compared to the Scenario Set 1 baseline, T-AKE SL experiences a 0.04% increase in expected service level. Concurrently, the expected value of Pallet Output is increased by 73 pallets annually. As a percentage of pallet throughputs, the new magazine positively affects the system annually by approximately 0.1%. Considering that there is overlap of the MOE confidence intervals between Scenarios 1 and 3, the effect of the new magazine on the system is insignificant and possibly attributable to the model variance.

The lack of significant difference in outcomes between Scenario Sets 1 and 3 indicates that simply changing the distance that either containerized or break-bulk has to travel does not produce a noticeable effect in the MOEs. Looking at system performance in broader terms, Figure 37 shows the comparison of the annual expected values for the MOEs and their measurable differences.

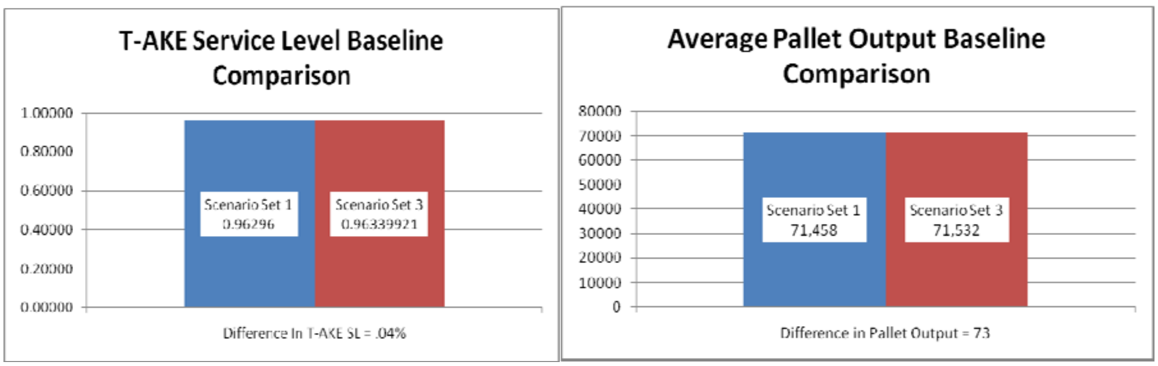


Figure 37. Scenarios 1 and 3 MOE Annual Average Value Comparisons.

In summary, Scenario Set 3 shows very little difference from Scenario Set 1 in either MOE. This result provides insights into the efficiency of the operation. The distance travelled in the process does not appear to have a significant effect on the efficiency of the process. This is an important finding because it shows that even in the best-case scenario of no competing requirements, changing the distance ordnance has to travel is not a critical path to improving either T-AKE SL or Pallets Out. Eliminating distance as a factor, only leaves the volume of ordnance operations capable as an area of interest. Specifically, in Scenario Set 5, this thesis looks into the available resource aspect of the problem.

5. Analysis of Scenario Set 4 – Simulating Completion of Magazine on Orote

This section begins with a comparison of Scenario Sets 3 and 4. Upon the addition of competing requirements to the system, quantitative measurement of the effect on the system is measured. Comparing this scenario against the baseline scenario shows the immediate quantitative results of competing requirements. Figure 38 shows the comparison of the distributions of Scenario Sets 3 and 4 T-AKE SL.

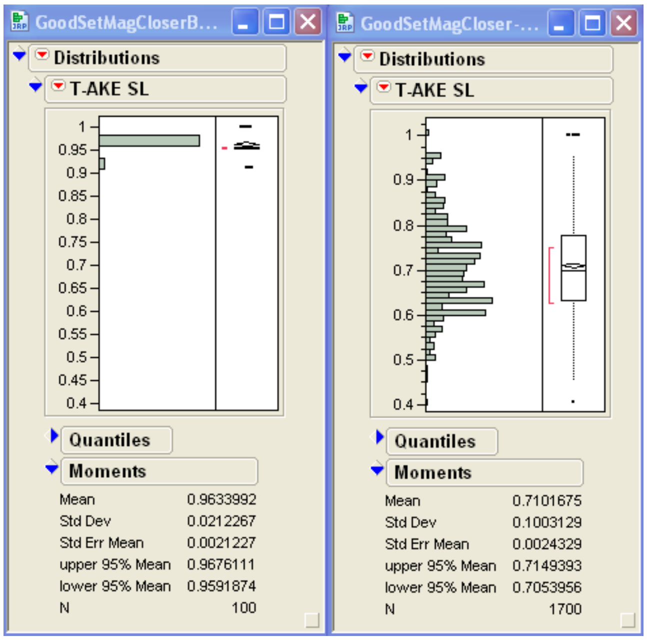


Figure 38. Scenario Sets 3 and 4 T-AKE SL Distribution Comparisons.

Considering that there is no overlap of the T-AKE SL confidence intervals between Scenarios 1 and 2, the impact of competing requirements on the system is significant and not attributable to the model variance. The New Magazine with Competing Requirements scenario produced a mean T-AKE SL of 71.02%, with a 95% confidence interval of (70.53, 71.49). When compared to the baseline, T-AKE SL sees an effect of 25.33% reduction in expected service level.

The New Magazine with Competing Requirements scenario also produced a mean Pallets Out value of 57910.70 pallets, with a 95% confidence interval of (57445.53, 58375.86). When compared to the baseline, T-AKE SL sees an effect of 25.32% reduction in expected service level. Concurrently, the expected value of pallet output is reduced by 13,621 pallets annually. As a percentage of reduction in pallet throughput, competing requirements influence the system by approximately 19.04%. A comparison of Pallets Out is seen in Figure 39.

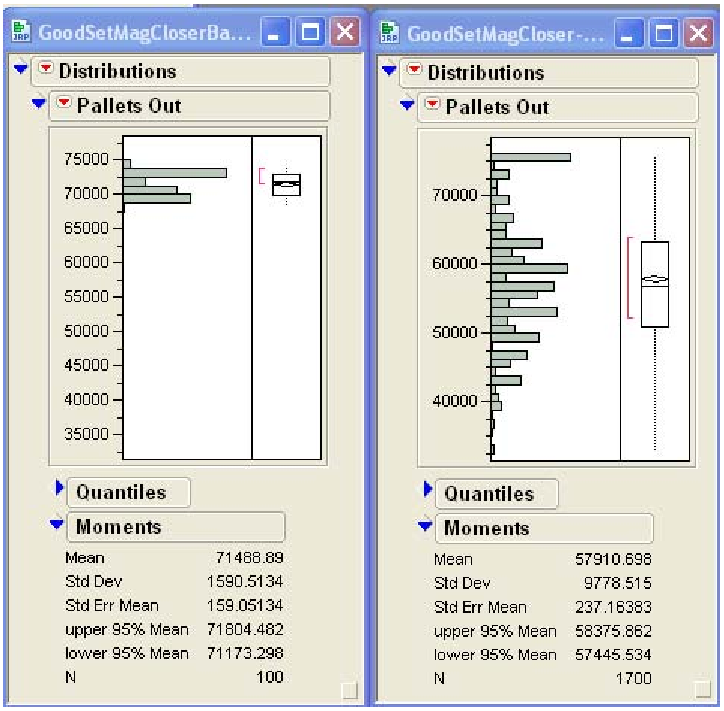


Figure 39. Scenario Sets 3 and 4 Pallets Out Distribution Comparisons.

Looking at system performance in broader terms, Figure 40 shows the comparison of the annual expected values for the MOEs and their measurable differences.

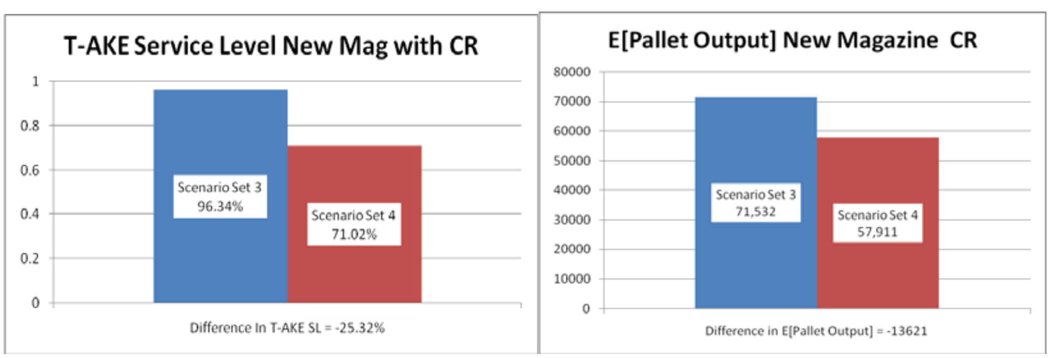


Figure 40. Scenarios 3 and 4 MOE Annual Average Value Comparisons.

Considering that there is no overlap of the MOE confidence intervals between Scenarios 3 and 4, as seen in Figures 38 and 39, the impact of competing requirements on the system is significant and not attributable to model variance.

The next step in the analysis is to compare Scenario Sets 4's MOEs to those in Scenario Set 2. Scenario Set 4 mirrors Scenario Set 2 as the baseline comparisons did in the previous analysis. This gives a comparison of the current system and the system that will exist when the new magazine construction is completed. Figure 41 shows the distributions of the Scenario Set 2's and 4's MOEs.

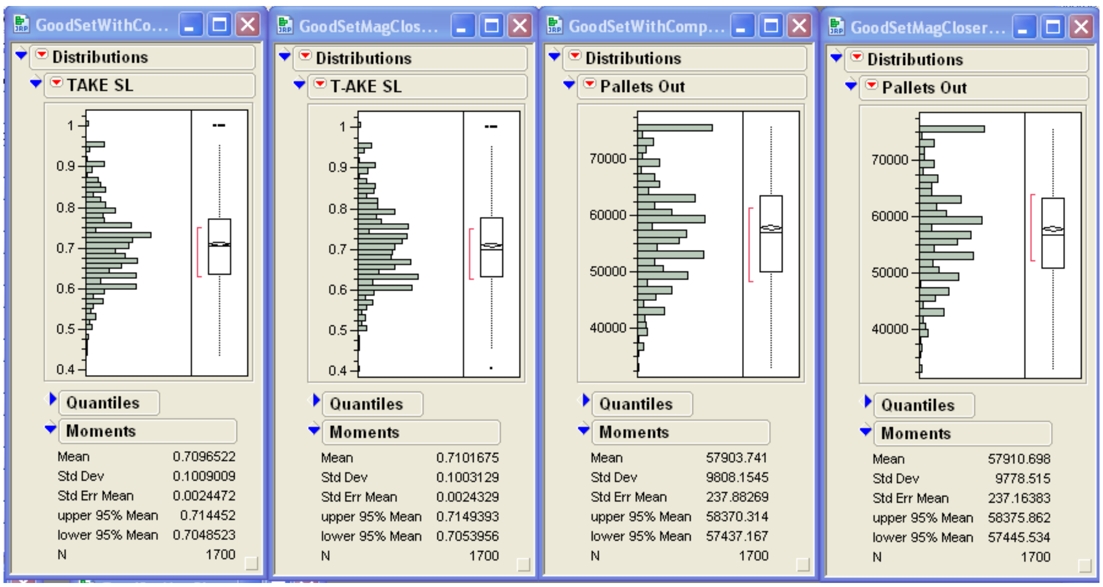


Figure 41. Scenario Sets 2 and 4 – MOE Distributions.

The lack of significant difference in outcomes between the Scenario Sets 2 and 4 indicates that simply changing the distance that either containerized or break-bulk has to travel does not produce a noticeable effect in the MOEs. These results are very similar to the results comparing Scenario Sets 1 and 3. Looking at system performance in broader terms, Figure 42 shows the comparison of the annual expected values for the MOEs and their measurable differences.

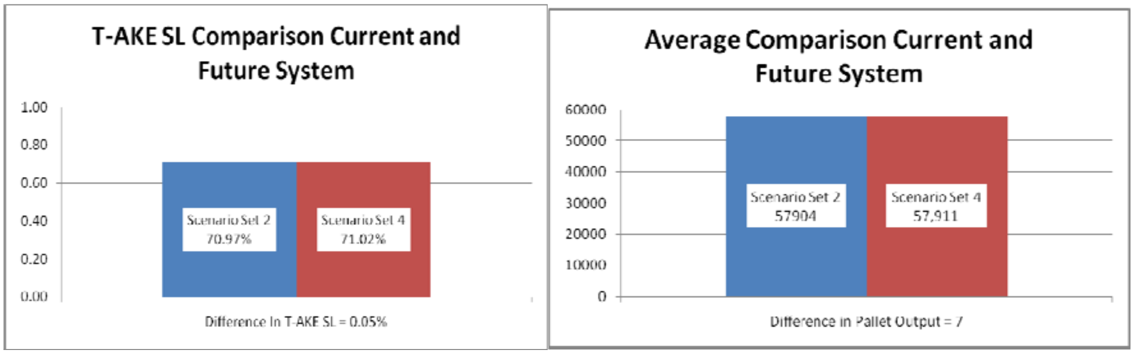


Figure 42. Scenarios 2 and 4 MOE Annual Average Value Comparisons.

This is an extremely insightful finding when considering the cost of building the new magazine. Estimating costs for the magazine are stated at $76M (NAVBASE GUAM DD Form 1392, 2005). Using these estimates and the results of this thesis, the projected cost is $1.04M per pallet improvement. These calculations do not consider the return on investment over time, but they do suggest that further simulation and modeling of the system and its infrastructure are required before further capital invenstment occurs. These calculations also do not consider the explosive safety issues that are considered when making infrastructure investments of this size. Setting these exceptions aside, the results still provide a strong argument for using simulation and modeling to assist in the decision-making process. Table 10 calculates Average Pallet Output difference between Scenario Sets 1and 3, as well as Scenario Sets 2 and 4.

Table 10. Average Annual Pallet Throughput Calculations.

	Baselines SS 1 & 3	Competing Requirements SS 2 & 4
Future with Closer Magazine	71532	57911
- Current System	71458	57904
Average Pallet Output	73	7

By quantifying the significant impact of competing requirements on the system, the next step in analysis of this scenario is to explore the factors in the model that are possible contibutors to this effect. In order to identify these possible significant factors, both regression analysis and the nonparametric method of regression tree partitioning is used to see if any particular factors in the model are significant. Each MOE is evaluated using this method.

In the Step History table, a stepwise regression analysis of both Scenario Set 4 MOEs indicates the order in which the terms entered the model and shows the effect, as reflected by RSquare. The significant factors in the set are *v_TAKE_Arr_Cycle*, *v_percent_unstuffed_pier*, *v_OCS_Arr_Cycle*, and *v_percent_Navy_Cont*. Figure 43 is the JMP output for a stepwise regression analysis of Scenario Set 2.

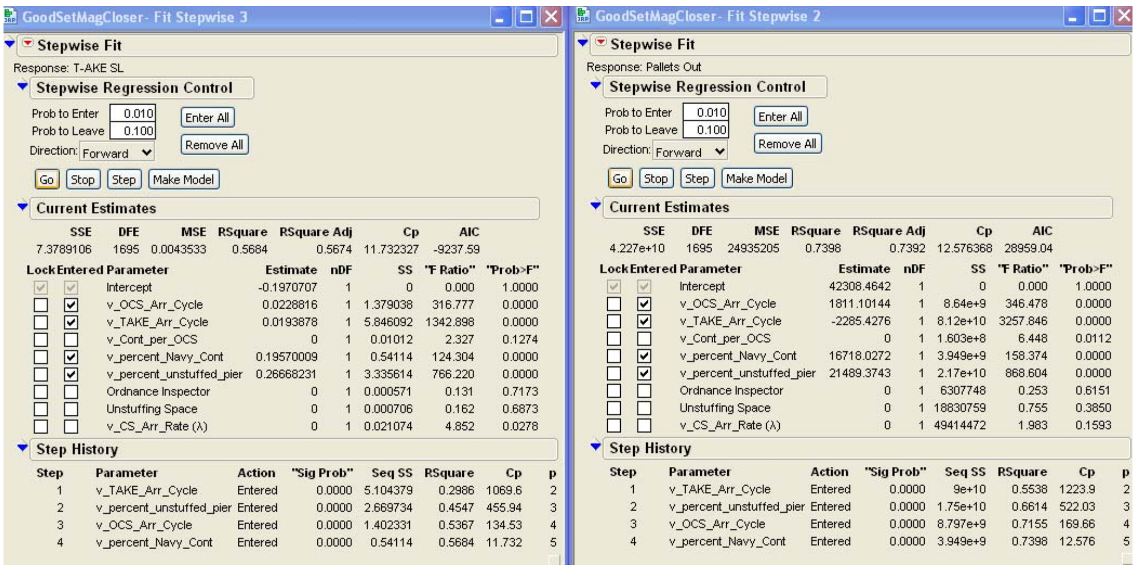


Figure 43. Stepwise Regression Analysis of Scenario Set 4.

Using this analysis, *v_TAKE_Arr_Cycle* is the largest contributing factor for both MOEs. In the case of T-AKE SL, for every additional day added to the *v_TAKE_Arr_Cycle* interval, the service level increases by approximately 2%. This result makes sense, in that, as the number of T-AKEs that enter the system goes down, the traffic intensity seen at Kilo Wharf decreases and allows for fewer ships in the queue. Fewer ships in the queue translates into increased chances of reaching Kilo Wharf and completing service. In the case of Pallets Out, for every additional day added to the *v_TAKE_Arr_Cycle* interval, the number of Pallets Out decreases by approximately

2,300 pallets. This result also makes sense. As fewer T-AKEs enter the system, the opportunity for T-AKEs to load pallets also decreases. These results are very similar to those seen in Scenario Set 2.

The factor, *v_OCS_Arr_Cycle*, contributes to the T-AKE SL, with the same logic as *v_TAKE_Arr_Cycle*. More OCSs equates to more chances of waiting in the queue and less chance of being served. However, when considering Pallets Out, *v_OCS_Arr_Cycle* has a reciprocal effect. As the arrivals of OCSs becomes more spread out, more T-AKEs are able to be served and, therefore, Pallet Out increases.

The analysis differs from Scenario Set 2 in that the factor *v_percent_unstuffed_pier* has replaced *v_Cont_per_OCS* as a contributing factor. This is is very interesting, considering the specific scenario. In this scenario, the magazine is closer and yet there appears to be a benefit to increasing the amount of ordnance that is processed pier-side.

Figure 44 is the regression analysis of Scenario Set 4's MOEs. The analysis of Scenario Set 4 T-AKE SL indicates by a Prob>|t| that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_CS_Arr_Time*, *v_percent_Navy_Cont*, and *v_percent_unstuffed_pier*. Similarly, regression analysis of Scenario Set 4 MOE Pallets Out indicates by a Prob>|t| that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_CS_Arr_Time,* *v_Cont_per_OCS*, *v_percent_Navy_Cont*, and *v_percent_unstuffed_pier*. Each of these regressions tells a story about the system and the influence of the identified factors. For example, every unit percent increase in *v_percent_unstuffed_pier* positively influences the system by 0.266 in service level. Therefore, this analysis indicates that unstuffing pier-side in this scenario is an efficient process that increases T-AKE SL. Another example is for every *v_TAKE_Arr_Cycle* unit added, the Pallets Out is influenced negatively by 2273.359 pallets. Logically, this makes sense, in that the further apart arrivals are to the wharf, the fewer pallets are able to leave the system. Therefore, an ideal cycle time for T-AKEs will limit congestion, while maximizing pallet output.

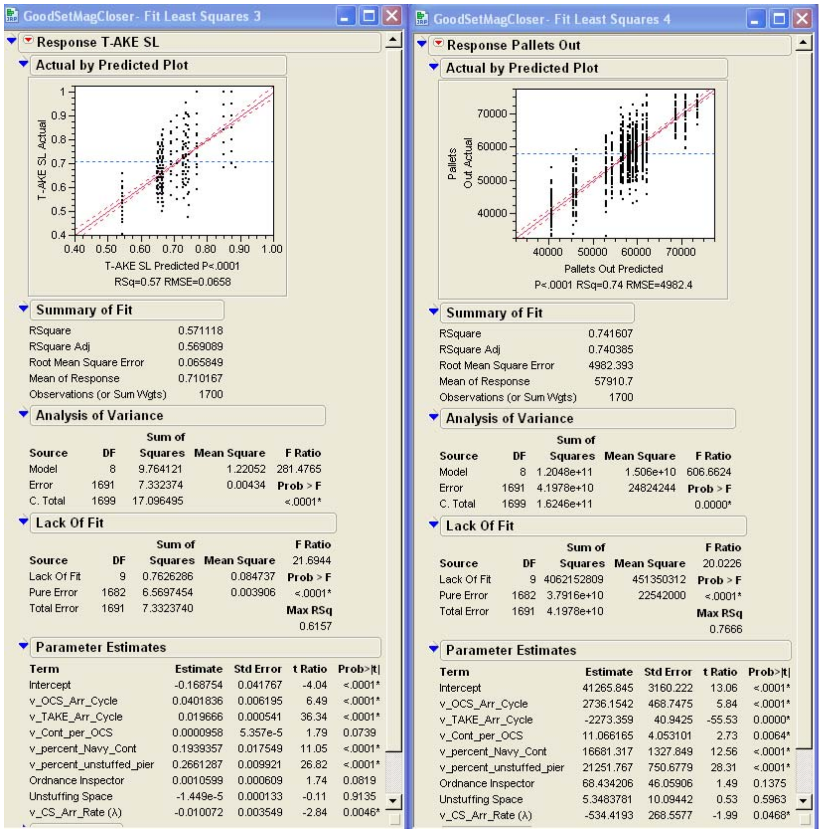


Figure 44. Regression Analysis of Scenario 4.

The results of the regression analysis direct the focus of the nonparametric analysis that follows. Using a method similar to that used in Scenario Set 2 analysis, a decision to determine the approriate number of partitions is accomplished by plotting the RSquare values by partition to find a point of diminishing returns. An initial number of 10 partitions is used to evaluate the RSquare. Figure 45 shows the RSquare plot for Scenario Set 4 partitions and indicates where the diminishing returns are observed for further partitions.

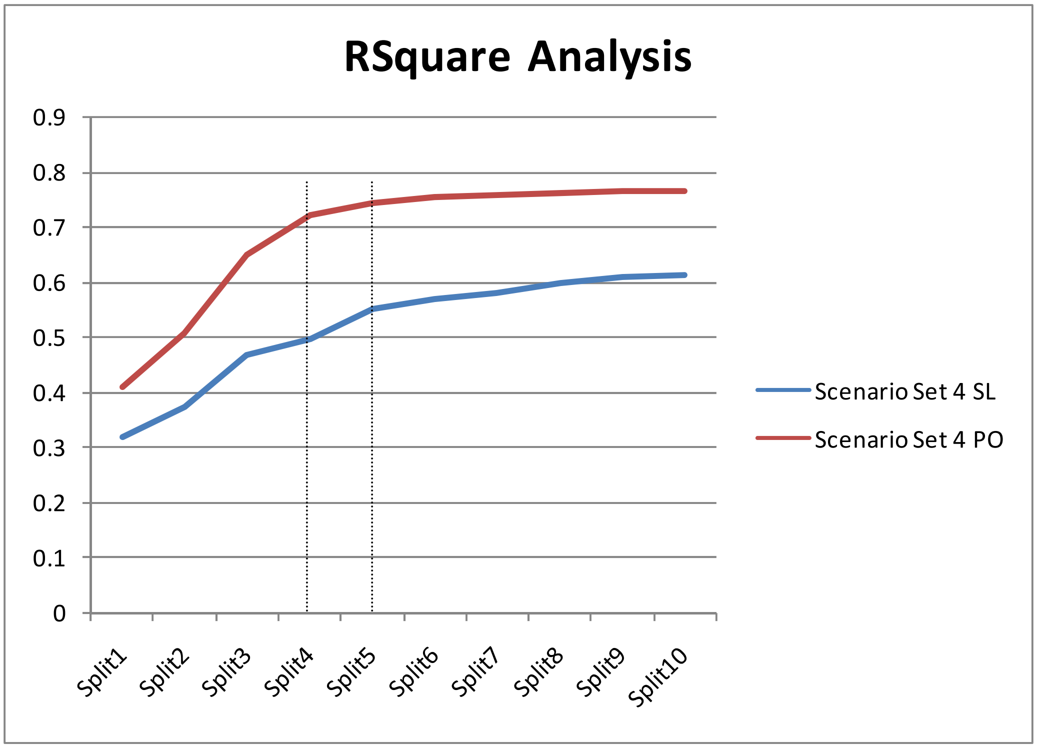
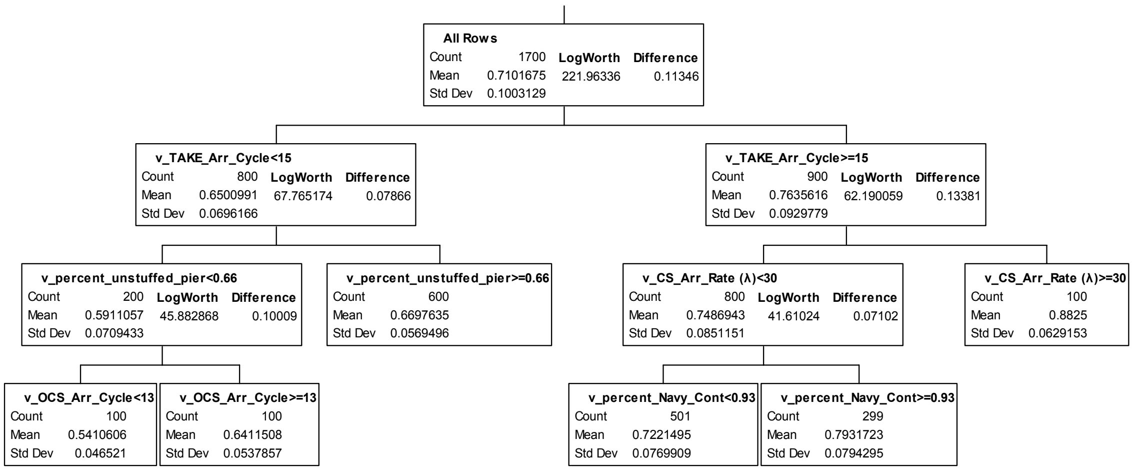


Figure 45. RSquare Plot for Scenario Set 4 Partitions.

By evaluating the 10 partitions, the bend in the curve for both MOEs occurs between the fourth and fifth split for each MOE. Using this information, each MOE is evaluated through the fifth partition. Using the regression analysis previously conducted, along with the partition trees, provides insights into how the significant factors involve themselves in the system under certain conditions. Figure 46 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	1	0.50090228
v_TAKE_Arr_Cycle	1	5.4524101
v_Cont_per_OCS	0	0
v_percent_Navy_Cont	1	0.94452705
v_percent_unstuffed_pier	1	0.92805747
Ordnance Inspector	0	0
Unstuffing Space	0	0
v_CS_Arr_Rate (λ)	1	1.59146405
Total	5	9.41736095

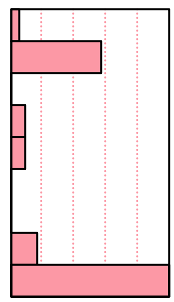
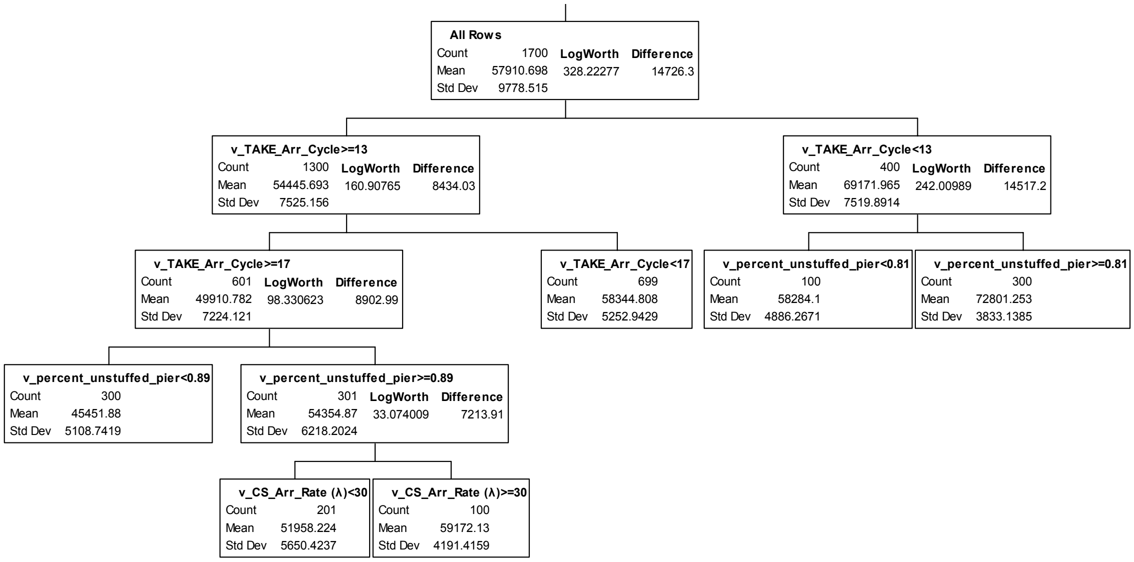


Figure 46. Partition and Column Contribution of T-AKE SL in Scenario 4.

The largest contributor through five partitioning splits is the decision factor, *v_TAKE_Arr_Cycle*. The next largest contributor is now the competing requirement, *v_CS_Arr_Time*. Both of these factors are expected to influence T-AKE SL because larger spacing of interarrival times creates a decrease in traffic intensity. A decrease in traffic intensity gives the server more opportunity to serve each arrival to the system.

The competing requirement, *v_percent_Navy_Cont*, does appear again as a contributor, but interestingly, *v_percent_unstuffed_pier* is a larger contributor. This is an interesting insight because the splits where *v_percent_unstuffed_pier* appear are based on the *v_TAKE_Arr_Cycle* and are far apart. For *v_TAKE_Arr_Cycle* less than every 15 days, the split for *v_percent_unstuffed_pier* occurs at 66%. On the other hand, for a *v_TAKE_Arr_Cycle* greater than or equal to 15 days and v_CS_Arr_Time less than 30, the split for *v_percent_unstuffed_pier* occurs at 93%. By definition of the contingency that establishes the scenario, this would limit T-AKE interarrival times, while enduring CS requirements near what they have been historically. Otherwise, once *v_TAKE_Arr_Cycle* is less than 15, the results indicate that the current practice of unstuffing as close to 100% of containers possible pier-side may not be the best practice. Figure 47 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	0	0
v_TAKE_Arr_Cycle	2	8.9321e+10
v_Cont_per_OCS	0	0
v_percent_Navy_Cont	0	0
v_percent_unstuffed_pier	2	2.7715e+10
Ordnance Inspector	0	0
Unstuffing Space	0	0
v_CS_Arr_Rate (λ)	1	3475125828
Total	5	1.2051e+11

Figure 47. Partition and Column Contribution of Pallets Out in Scenario 4.

Again, the largest contributor through five partitioning splits is the decision factor, *v_TAKE_Arr_Cycle*. In this MOE analysis of the competing requirement factors, *v_CS_Arr_Time*, is the only one shown as a contributing factor. Just as in the analysis on the T-AKE SL partition, *v_percent_unstuffed_pier* is a large contributor in the Pallets Out partition.

In summary, Scenario Set 4 quantifies the impact of including competing requirements to the system as a reduction in T-AKE SL by 25.32% and Pallets Out by 19.04%. Scenario Set 4 also indicates that *v_percent_unstuffed_pier* is the strongest candidate as the critical factor to have the greatest effect on the system.

6. Analysis of Scenario Set 5 – Exploratory Set

Scenario Set 5 begins the exploration of the system beyond the competing requirements examined in the previous scenarios. Introducing a few resource capacities, this scenario primarily focuses more on the possible outcomes, with the acquisition of resources. Upon the addition of these new input parameters to the system, quantitative measurement of effect on the system is calculated. Figure 48 shows the distributions of the Scenario Set 5's MOEs.

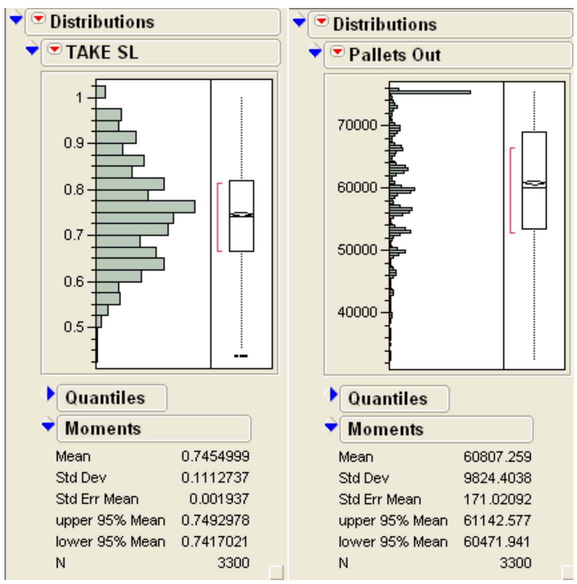


Figure 48. Scenario Set 5 – The Exploratory Model MOE Distributions.

The Exploratory scenario produced a mean T-AKE SL of 74.55%, with a 95% confidence interval of (74.17, 74.93). It also produced a mean Pallets Out value of 60,807 pallets, with a 95% confidence interval of (60,472, 61143). When compared to the baseline, T-AKE SL sees an effect of 21.75% reduction in expected service level. Concurrently, the expected value of pallet output is reduced by 10,651 pallets annually. As a percentage of reduction in pallet throughput, competing requirements negatively influence the system by approximately 14.91%. These results are slight increases in comparison to the results seen in Scenario Set 2 which had fewer variable input parameters. This result is expected because allowing for additional resources available to the system provides the system with more possible configurations in which to operate as best as possible. Figure 49 shows the MOE comparisons between Scenario Sets 1, 2, and 5.

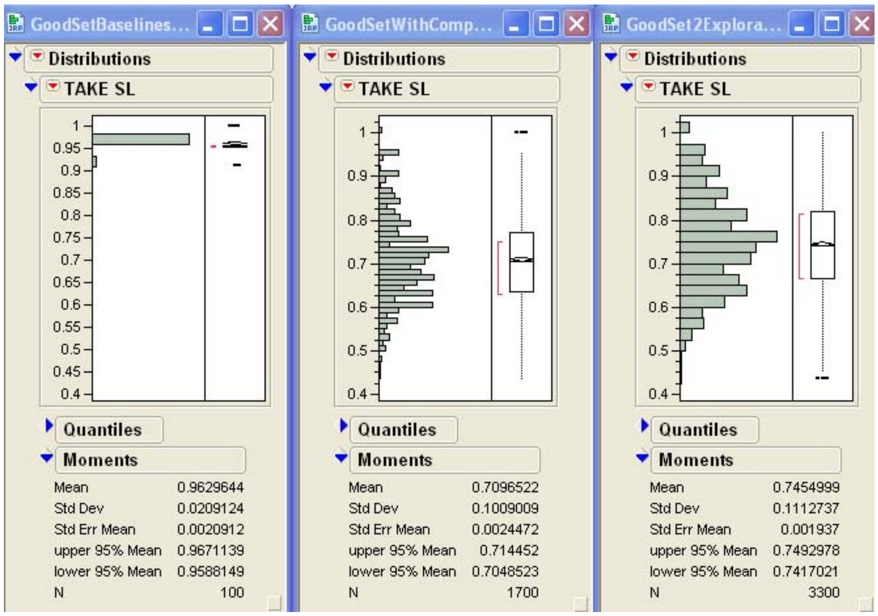


Figure 49. Scenario Sets 1, 2, and 5 T-AKE Distributions.

Considering that there is no overlap of the T-AKE SL confidence intervals between Scenario Sets 1 and 5, the effect of competing requirements on the system is significant and not attributable to the model variance. When considering the differences between Scenario Sets 2 and 5, the initial overall indication is that there is some positive effect from the additional resources available to the system. Figure 50, which shows this slight increase, displays the mean MOEs.

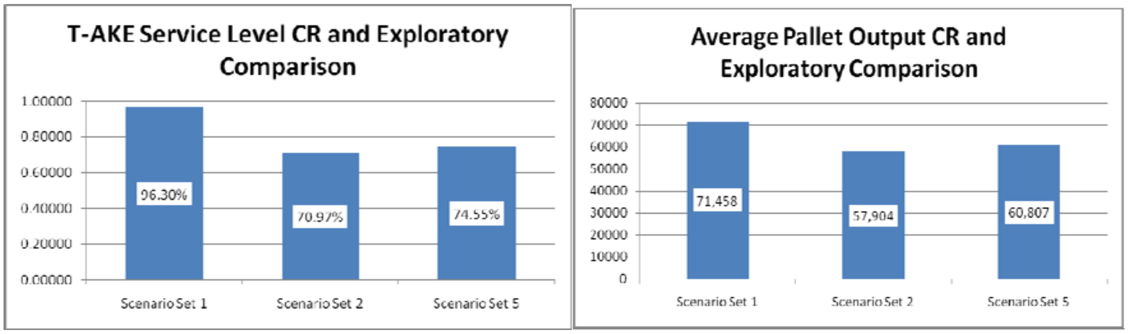


Figure 50. Scenarios 1, 2, and 5 MOE Annual Average Value Comparisons.

However, the lack of a practical, significant difference in outcomes between Scenario Sets 2 and 5 indicates that simply adding more resources does not produce a statistically significant effect in the MOEs. Conversely, this experiment limited the number of resources possible in the system. This provides a great opportunity for future studies to explore the bounds of resource allocation limits and their effects on the system. Possible candidates for this research may come to light later in this chapter, when critical factors are identified through regression analysis and partition trees.

By quantifying the significant effect of competing requirements on the system, the next step in the analysis of this scenario is to explore the factors in the model that are possible contibutors to this effect. In order to identify these possible significant factors, both regression analysis and the nonparametric method of regression tree partitioning are used to see if any particular factors in the model are significant. Each MOE is evaluated using this method. Figure 51 is the JMP output for the regression analysis of Scenario Set 5.

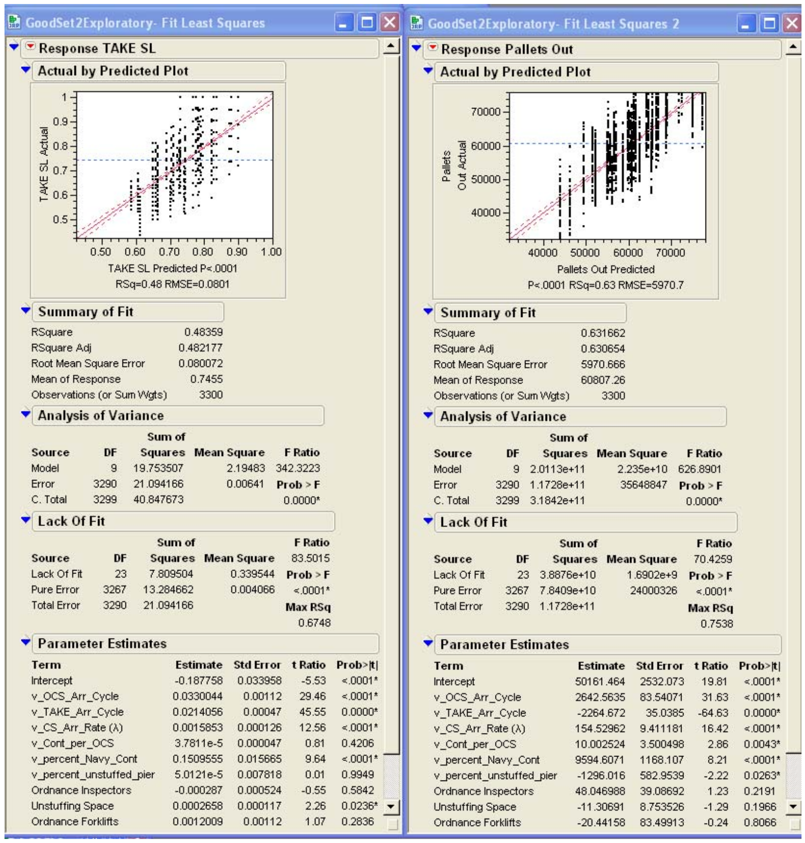


Figure 51. Scenario Set 5 Main Effects Regression.

Regression analysis of Scenario Set 5 MOE T-AKE SL indicates by a Prob>|t| that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_CS_Arr_Time* , *v_Cont_per_OCS*, *v_percent_Navy_Cont*, and *Unstuffing Space*. Similarly, regression analysis of Scenario Set 5 MOE Pallets Out indicates by a Prob>|t| that the significant factors in the model are *v_OCS_Arr_Cycle*, *v_TAKE_Arr_Cycle*, *v_CS_Arr_Time*, *v_Cont_per_OCS*, *v_percent_Navy_Cont*, and *v_percent_unstuffed_pier*. Each of these regressions tells a story about the system and the influence of the identified factors. For example, for every *v_TAKE_Arr_Cycle* unit added, the T-AKE SL is influenced positively by 2.1%, and the Pallets Out is influenced negatively by 2265 pallets.

The results of the regression analysis direct the focus of the nonparametric analysis that follows. Using a method similar to that used in Scenario Set 2 analysis, a decision to determine the approriate number of is accomplished by plotting the RSquare values by partition to find a point of diminishing returns. An initial number of 10 partitions is used to evaluate the RSquare. Figure 52 shows the RSquare plot for Scenario Set 5 partitions and indicates where the diminishing returns are observed for further partitions.

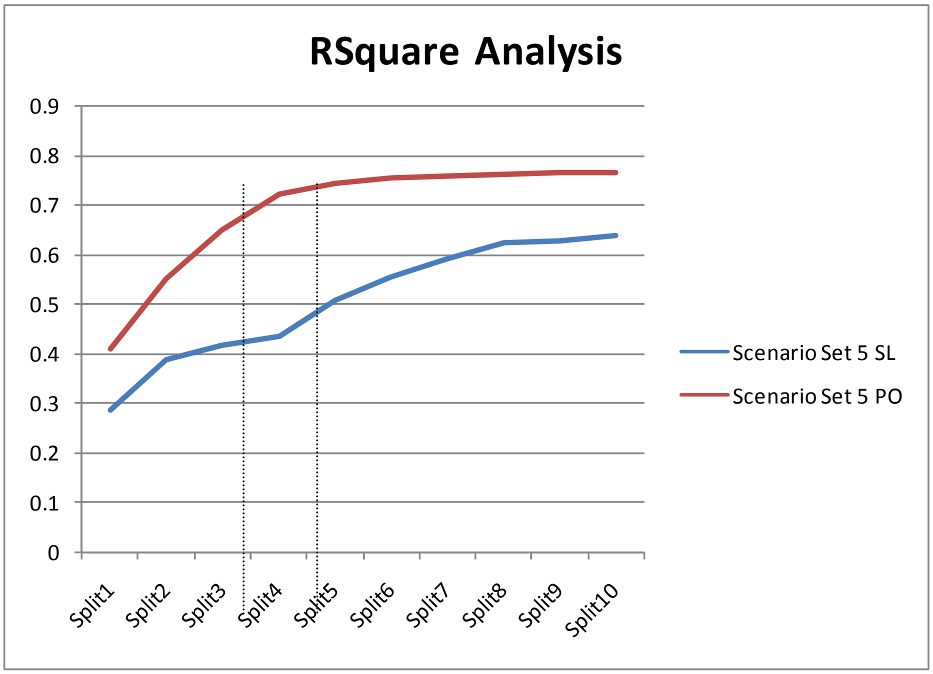
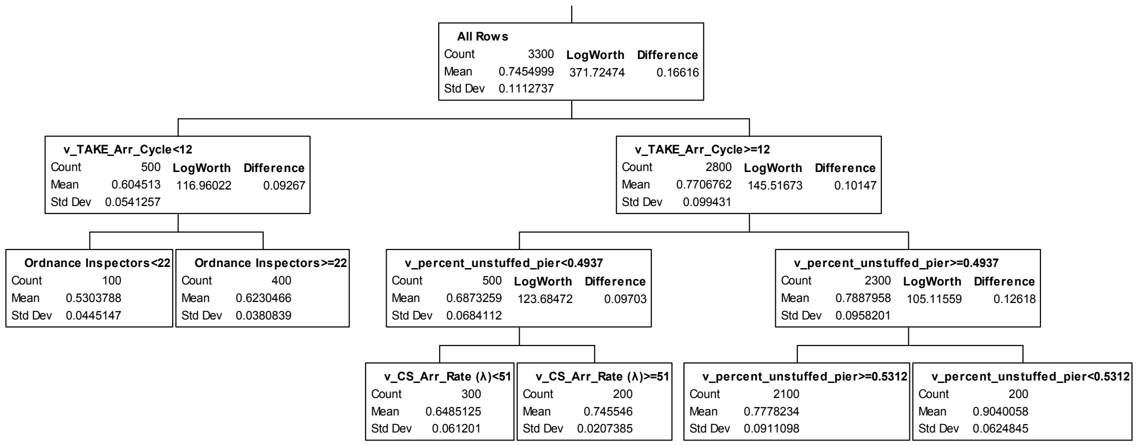


Figure 52. RSquare Plot for Scenario Set 5 Partitions.

By evaluating the 10 partitions, the bend in the curve for the Pallets Out MOE occurs between the fourth and fifth split. The RSquare values for T-AKE SL appear to have two breakpoints, where the first occurs after the second split and the next after the eigth split, with a significant slope increase at the fourth split. Using this information, each MOE is evaluated through the fifth partition. Using the regression analysis previously conducted, along with the partition trees, provides insights into how the significant factors involve themselves in the system under certain conditions. Figure 53 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	0	0
v_TAKE_Arr_Cycle	1	11.7134192
v_CS_Arr_Rate (λ)	1	1.12985923
v_Cont_per_OCS	0	0
v_percent_Navy_Cont	0	0
v_percent_unstuffed_pier	2	7.13626954
Ordnance Inspectors	1	0.68698527
Unstuffing Space	0	0
Ordnance Forklifts	0	0
Total	5	20.6665333

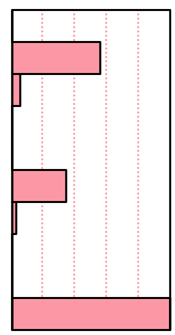
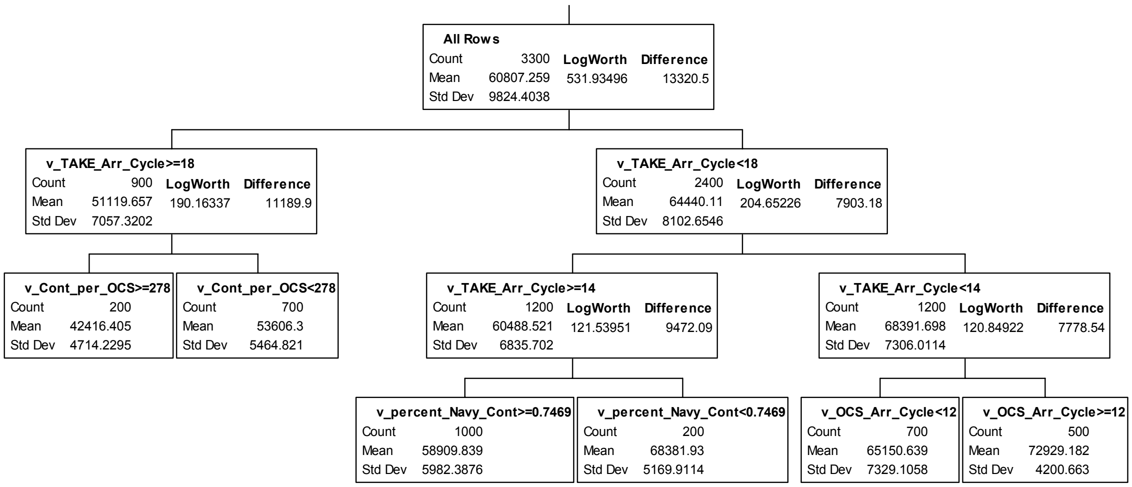


Figure 53. Partition and Column Contribution of T-AKE SL in Scenario 5.

Through five partitioning splits for T-AKE SL, the major contributors are *v_TAKE_Arr_Cycle*, *v_CS_Arr_Time*, *v_percent_unstuffed_pier*, and *Ordnance Inspectors*. The largest contributor through five partitioning splits is the decision factor, *v_TAKE_Arr_Cycle*. The next largest contributor is *v_percent_unstuffed_pier*, followed by *v_CS_Arr_Time* and *Ordnance Inspectors*. The are many interesting insights found in this analysis. The first is that the only competing requirement to contribute at this point is *v_CS_Arr_Time*, and it does so fractionally, compared to other contributors. The second interesting insight is the influence of *v_percent_unstuffed_pier*. The regression analysis of T-AKE SL did not signify *v_percent_unstuffed_pier* as a significant factor.

Another interesting insight is in the second tier of the partition tree. As the *v_TAKE_Arr_Cycle* gets larger (farther apart) the factor that contributes most to the next split is *v_percent_unstuffed_pier*. On the other hand, when *v_TAKE_Arr_Cycle* gets smaller (closer together) the factor that contributes most to the next split is *Ordnance Inspectors*. This result makes sense, in that, when T-AKEs arrive at larger intervals there is less competition at the wharf; therefore, the most expeditious method of processing containers is best. Whereas, when they arrive at tighter intervals, the most expeditious method of unstuffing provides the best results because the containers are transformed into pallets and more readily available for the arriving T-AKEs. Figure 54 displays the partitioning and column contributions of the factors.



Column Contributions

Term	Number of Splits	SS
v_OCS_Arr_Cycle	1	1.7648e+10
v_TAKE_Arr_Cycle	2	1.5362e+11
v_CS_Arr_Rate (λ)	0	0
v_Cont_per_OCS	1	1.9478e+10
v_percent_Navy_Cont	1	1.4953e+10
v_percent_unstuffed_pier	0	0
Ordnance Inspectors	0	0
Unstuffing Space	0	0
Ordnance Forklifts	0	0
Total	5	2.0569e+11

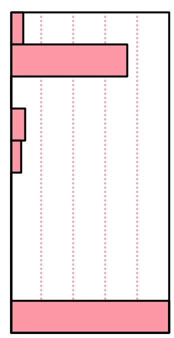


Figure 54. Partition and Column Contribution of Pallets Out in Scenario 5.

Through five partitioning splits for Pallets Out, the largest contributors are the decision factors, *v_TAKE_Arr_Cycle*, *v_OCS_Arr_Cycle*, *v_Cont_per_OCS*, and *v_percent_Navy_Cont*. The results are sensible, in that, *v_TAKE_Arr_Cycle* relates to how often a T-AKE arrives to pick up pallets of ordnance. Further, both *v_percent_Navy_Cont* and *v_Cont_per_OCS* relate to the congestion at the wharf. Notice in the partition tree of Figure 54 that the system performs better when both of these factors are smaller. Granted, these factors also contribute to the number of containers and subsequent pallets that are available in the system, but because of the initial inventory carried they do not affect the system in this manner. Without this initial inventory, those factors would have substantial influence because they directly influence the supply coming into the system.

a. Process Analyzer Results

Using these insights, the decision factors are again analyzed by comparing the outputs of the independent input scenarios in Scenario Set 5 to the findings in the partition analysis. The Arena Process Analyzer provides response (MOE) charts identifying the "best" scenario within the set. Since T-AKE SL is calculated in the data post processing from the T-AKE In and TAKE Out responses, the chart directly from the Process Analyzer is unavailable. However, Pallets Out is readily available for analysis in the Process Analyzer. Therefore, considering that Pallets Out is the MOE that most directly relates to combat potential in the AOR, this thesis uses it as the MOE of interest in this section. Figure 55 is a box and whisker chart that identifies Scenario 15, followed closely by Scenario 11 as the "best" scenarios to maximize the MOE in Scenario Set 5.

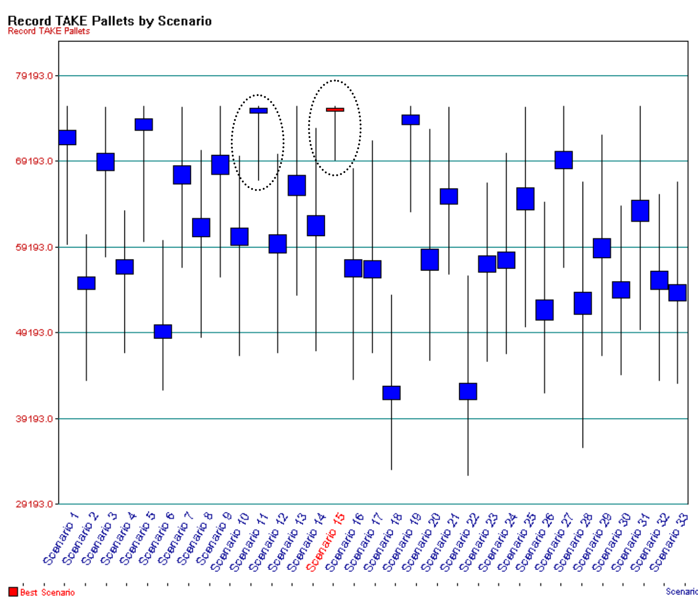


Figure 55. Pallet Out Best Scenario in Scenario Set 5.

To gain insights into why these scenarios were the top performers, the scenario inputs are examined. Table 11 extracts the scenarios of interest from the NOLH used in Scenario Set 5.

Table 11. Scenario Set 5 “Best” Input Parameters.

Scenario	v_OCS_Arr_Cycle	v_TAKE_Arr_Cycle	v_CS_Arr_Rate (λ)	v_Cont_per_OCS	v_percent_Navy_Cont	v_percent_unstuffed_pier	Ordnance Inspectors	Unstuffing Space	Ordnance Forklifts
111	12	12	51	297	0.80	0.44	19	135	9
115	12	12	54	291	0.81	0.40	25	149	11

The parity between the scenarios is the first noticeable finding. By applying an appropriately offset matching cycle between OCSs and T-AKEs, the cycle can be as few as every 12 days, which is less than the requirement of every 16 days, at most, for T-AKEs involved in supporting forces in the contingency. To accomplish this, an increase in the time between CS arrivals is required in order to reduce the traffic intensity at the wharf. This would require a policy that involved using waivers to moor the CSs that are ordnance-laden at other piers not commonly used by this type of vessel. In order to accommodate the changes in OCS and T-AKE cycle times, the number of containers offloaded requires an increase of 16.5% over the 255 containers suggested in previous studies, pushing this value into the 290 range seen in Table 11. Of these containers offloaded, the Navy could support up to 20% competition from the Air Force for the ordnance coming into Guam. The biggest change in this scenario from current operating policy is in the amount unstuffed pier-side. By reducing this number by more than 50%, these results are acheivable under resource conditions very close to those that presently exist. The current capacities for the remaining resources in Scenario 11 vary slightly from their low level inputs and would all be feasible during a contingency. In Scenario 15, where the resource capacities are higher, they are proportionally higher in relation to the increase in Unstuffing Space. More available Unstuffing Space can only provide positive effects to the system, if there are ordnance inpsectors to process the ordnance and forklifts to move the pallets.

In summary, Scenario Set 5 quantifies the effect of including competing requirements to the system as a reduction in T-AKE SL by 25.33% and Pallets Out by 18.97%. Scenario Set 5 also indicates that *v_percent_unstuffed_pier* is the critical factor required to change the most in order to maximize pallet throughput.

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V. CONCLUSIONS

A. THESIS SUMMARY

This thesis set out to explore the impact of competing requirements on the ordnance operations currently available in the Asian Pacific Theater. Through the combination of previous studies, the development of a realistic scenario, an Arena-based simulation model, and thorough experimentation and analysis; this thesis produced a quantitative analysis of the challenges involving the movement of ordnance into an AOR of concern. The simulated movement and ordnance operations generated by this thesis provide a strong argument for logistics, infrastructure, and resource allocation modeling in future decision-making processes. This thesis also provides a strong foundation for future study of the challenge of moving ordnance into the Asian Pacific Theater.

B. THESIS QUESTIONS

The goal of this thesis was to answer the following questions:

- How will introducing the competing requirements affect the predicted capabilities of the ordnance operations in Guam?
- What are the critical factors in the ordnance operations process?

This section briefly summarizes the answers to these questions.

1. Effect of Competing Requirements

The simulation experiment results showed that introducing two forms of viable competition into the system has a statistically significant effect on both the T-AKE service level and pallet throughput of the system. The impact of these effects held true for the current system and the system that includes the new magazine on Orote Peninsula. T-AKE service level in the current system is reduced by an average value of 26% reduction in service level with a maximum value of 52%. This means that on average 1 of every 4 T-AKEs that enter the system is not serviced by the system. The T-AKEs not serviced at the end of the simulation time are left in queue. Pallet throughput is reduced by an average of 13,555 pallets and a maximum of 41,167 pallets. This reduction in pallet output is equivalent to approximately four T-AKEs' worth of ordnance that is not delivered to the forward edge of the contingency.

2. Critical Factors

Regression analysis and partition tree analysis are used to analyze the simulation experiment results. Across the current and new systems, the primary critical factor for both is the arrival cycle of the T-AKE. A greater T-AKE arrival cycle, T-AKEs arriving further apart, consistently caused the system to see a reduction in pallet throughput. The analysis results also suggest that setting the arrival cycle of the T-AKE and the OCS to the same interval, but with sufficient offset, reduces the impact of the competing requirements introduced to the system. The trade-offs to the optimal setting of the OCS and T-AKE arrival cycle are an increase in the number of containers offloaded from an OCS and a significant reduction in the number of containers unstuffed at Kilo Wharf.

Both competing requirements were found to have statistical significance across the different scenario sets, but in varying intensities. The impact from competing ships was seen more often affecting T-AKE service level, whereas competition for ordnance from the Air Force mostly affected the overall pallet throughput. The analysis results suggest that the T-AKE service level improves by implementing policies during a time of contingency that result in the mean arrival rate of competing ships to be greater than 30 days. It also suggests that keeping the competition for ordnance under 26% improves pallet throughput.

C. ADDITIONAL INSIGHTS

This thesis discovered several additional insights during the course of the experimentation and analysis. The three most significant are summarized in this section.

1. Initial Inventory

During the course of debugging the model, the initializing inventory required 75,000 pallets to keep the system from ever failing. The system is considered to fail when a T-AKE requests more pallets than in inventory. This translates to 150 million pounds of ordnance. This value was chosen after several tests were run and the initializing inventory was raised by 5,000 pallets each time, until the simulation ran to completion with no failures in 100 replications. No further experimentation was done with this value, but this does suggest that a certain inventory safety level is required to support a contingency of the magnitude in this thesis. This also suggests that the current capacity of the Ordnance Annex, which is 58 million pounds of munitions, may be insufficient to handle the variability of the scenario if a lesser value of initial inventory is the expected starting point in a contingency.

2. Operational Capacity

The operational capacity of the ordnance operations on Guam has been studied from a variety of approaches. An additional insight came to light using the simulation and modeling approach when the new magazine was modeled in the system. The simulation results indicate that there is no statistically significant difference between the system with the new magazine and the current system. Therefore, this component of the ordnance operations system is not considered a critical path. Although it seems logical that reducing the distance that ordnance has to travel would improve overall efficiency and throughput, it did not. The explanation found in the analysis is rooted in other critical factors. This insight provides for justification into using simulation and modeling research to investigate process and infrastructure improvements as a method of validating assumptions prior to expending large amounts of military construction funds.

3. Theater Challenges

The previous CNA and MSDDC studies, as well as this thesis, all indicate serious challenges when faced with moving a significant amount of ordnance or material through Guam. As this thesis developed, it was realized that having a single transshipment point for ordnance into the Asian Pacific Theater may be a serious issue, if its ordnance operations were somehow affected other than in ways introduced by our own military requirements. Alternative facilities in the Asian Pacific Theater are severely limited and eliminating Guam results in Hawaii being the western-most U.S. forward logistics base. That is a 3,320-nautical mile difference in forward presence.

D. RECOMMENDATIONS

Based on the conclusions of this thesis, several recommendations are made.

- Quantifying the impact of competing requirements to this system strongly promotes further research in to how to maximize the efficiency and throughput of the system. This information also suggests that incorporating alternative planning measures into the logistics planning portion of any major contingency in the Asian Pacific Theater is imperative. Variability and competition in the system are inevitable; therefore, future research is recommended to assist the Navy in developing measures to reduce the effect.
- The ordnance requirements at the forward battle edge will determine the T-AKE arrival cycle and are estimated based on the operational plan (OPLAN) used for the contingency. Pairing the information with the model in this thesis will provide decision makers with their best options for scheduling OCS arrivals and resource allocations at Guam. With limited T-AKEs in the Fleet, only a portion is assigned to the Asian Pacific Theater at any given time. In order to support the given OPLAN, it is recommended to use this model to assist in determining whether T-AKEs from other theaters are required in order to successfully achieve the desired T-AKE cycle.
- Dealing with the competing requirements primarily requires policy adjustments or joint coordination during the development of the OPLAN. By granting waivers and diverting competing ships to other wharfs, the Navy can achieve a mean CS interarrival time greater than 50 days and lessen the impact seen on ordnance operations at Kilo Wharf. It is also recommended that strategic coordination with the Air Force be carried out to ensure that their requirements are met, but do not exceed 20% of the incoming ordnance.
- The results of this thesis indicate that, under certain conditions, some of the current policies, such as the percent of containers unstuffed pierside, should be more flexible in order to maximize performance. The partition tree analysis approach is recommended for developing situational operating procedures when the given conditions exist. Adding flexibility to the policies that ordnance operations use, while maintaining safety considerations, shows improved performance of the system.
- The insights gained from this thesis have proven valuable to identifying system constraints and critical factors. Development of models similar to the one used in this thesis should be applied to other commodities vital to sustaining military contingencies. In particular, fuel requirements during a contingency display similar logistical challenges.

E. FOLLOW-ON WORK

The following is a list of valuable follow-on research that could be accomplished using this work.

- More detailed exploration and analysis into more robust input parameter ranges, to include realistically infeasible ranges in order to assess the cost of losing resource capacities, and the value of good policies.
- More detailed exploration and analysis into the best mix of resources for optimal performance when faced with the current competing requirements.
- More detailed exploration and analysis into best mix of resources for optimal performance, when faced with predetermined competing requirements.
- Focused analysis over the key parameters and ranges identified, including further analysis of parameter interactions.
- Analysis into the optimal level of initial inventory, to ensure a level of system viability when faced with the variability of the contingency. Essentially asking, "How low can the inventory be allowed to get before the system fails X percent of the time?"
- Exploration and analysis of other possible sites in the region, using the model as a framework for ordnance operations ashore.
- Analysis of the alternatives for a scenario that includes periods of unavailability to Kilo Wharf.

The following is a list of examples for follow-on research stemming directly from this thesis and the model.

- Analysis of new technology and resources on the ordnance operations process; specifically, analysis of the process with the proposed gantry crane on Kilo Wharf.
- Analysis of the provided contingency scenario for both shorter and longer periods of time. This would include extending the current model to account for resource maintenance and failures.
- Analysis and development of a recommended scheduling of vessel arrivals to optimize the throughput of the system, while providing for the ability to handle fluctuation of competing requirements.
- Extension of the model to include a dynamic queue that removes competing ships from the queue after a specified wait time (also known as "reneging"), as well as prioritizes OCSs and T-AKEs

Of the follow-on research listed above, the two that would provide the most insight into the system are:

New Technology and Resources—Guam's location makes it a cornerstone to success for contingencies in the Asian Pacific Theater. By applying new technologies and the best mix of resources to the system in Guam, every effort can be made to maximize its usefulness despite its limitations.

Dynamic Queue—The flexibility of United States forces has always played a hand in its military successes. Developing the current model into one that provides the decision maker with large-scale policy and resource flexibility by including a dynamic queue, will provide an entirely new dimension of analyzing this challenge.

APPENDIX: COMPONENT AND MODULE SPECIFICATION FOR THE MODELING ORDNANCE MOVEMENTS INTO THE ASIAN PACIFIC THEATER

A. INTRODUCTION

This specification is a document of the development and implementation of the simulation modeling necessary to address the existing and future ordnance operations systems at the Kilo Wharf on Orote Peninsula, Guam.

1. Document Organization

This document describes the model components and process modules used to simulate ordnance operations conducted at Kilo Wharf, and the proposed operations upon completion of the military construction (MILCON) project to build a magazine on the Orote Peninsula. The description includes most of the detail necessary to develop an Arena simulation model of the operations.

This specification is divided into two sections. The first section defines the purpose of the document and the software and hardware required to run the Arena model. The second section describes the components and process modules used to build the Arena model.

a. Purpose of the Functional Specification

The purpose of this document is to describe the components and process modules used to build the Arena model at the level of detail required for modeling purposes. This provides documentation for interested readers to follow when examining the model in Arena.

2. Hardware and Software Requirements

The thesis is developed in the Microsoft Windows operating system environment. The software and hardware required to run the model include (Kelton, Sadowski, & Sturrock, 2007):

- Arena Standard Edition 10.0 or higher
- Microsoft Windows (latest version available)
- At least 30MB hard disk space

B. MODEL DESCRIPTION

The following sections define the model timeline and provide a “parts list” of components and modules used to build the model. All other amplifying information about the model development or modeling approach can be directed to the author or to the NPS SEED Center, http://harvest.nps.edu/.

1. Model Timeline

The model is able to simulate ordnance operations of different run lengths for different purposes. The base unit of time used in Arena will be one day and the standard run length is one year. Figure 56 is an overview shot of the model structure.

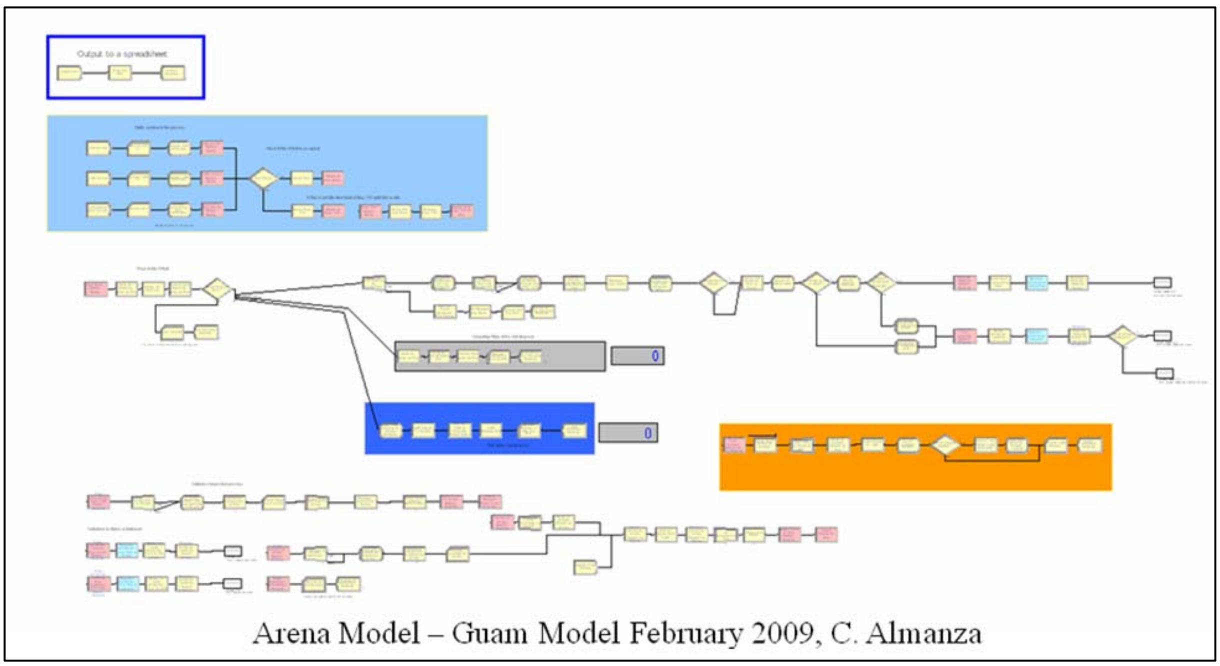

Figure 56. Model Structure Overview.

2. Model Components

This section describes all model components and modules used in this thesis. Each process tab in Arena and its related data modules are separately described to provide an easier method of following the descriptions.

Basic Processes

Create Modules	Description
OCS Arrives	An OCS Ship is first created at a time defined by the expression ANINT (UNIF (9, 13, v_Univ_Stream)). Following OCS Ships are created with an interarrival defined by v_OCS_Arr_Cycle.
TAKE Arrives	A TAKE Ship is first created at a time defined by the expression ANINT (UNIF (10, 21, v_Univ_Stream)). Following TAKE Ships are created with an interarrival defined by v_TAKE_Arr_Cycle.
Competing Ship Arrives	A Competing Ship is first created at a time defined by the expression ANINT (UNIF (1, 30, v_Univ_Stream)). Following OCS Ships are created with an interarrival defined by =-0.001 + EXPO (23.7, v_Univ_Stream) or v_CS_Arr_Rate.
Create Extra Pallets	The initial inventory of pallets, v_Initial_Inventory, is created at time 0.001 to preload the system. This is a onetime event for the model.
Output Out	This one-time entity is created at simulation end time (tfin) and enables the model to write output to a designated output file.
Dispose Modules	**Description**
Container Ship Disposal Module	This module disposes OCS Ship entities when they complete their respective processes in the system.
Competing Ship Disposal Module	This module disposes Competing Ship entities when they complete their respective processes in the system.
Error Dispose Module	This module disposes entities that fail to designate properly. This module is included as a debugging function.
TAKE Disposal Module	This module disposes TAKE Ship entities when they complete their respective processes in the system.
Dispose Air Force(AF) Containers Module	This module disposes Containers entities designated for the Air Force when they complete their respective processes in the system.
Pallet Disposal Module	This module disposes Pallet entities when they complete their respective processes in the system.
Output Dispose	This module disposes Entity 1 entities when they complete their respective processes in the system.
Process Modules	**Description**
CS Delay and Release Kilo	This process performs a Delay Release action on CSs for a delay period of UNIF(4.01, 7,v_Univ_Stream) days.
Crane Moves Container from Ship to Pier	This process performs a Seize Delay action on cranes for a delay period of UNIF(0.00735,0.01225,v_Univ_Stream) hours.
Ordnance Inspection at Ordnance Annex	This process performs a Seize Delay Release action on Ordnance Inspectors at the Ordnance Annex for a delay period of UNIF(0.13333,0.16667,v_Univ_Stream) hours.
Ordnance Inspection at	This process performs a Seize Delay Release action on Ordnance Inspectors at

Kilo	the Kilo Wharf for a delay period of UNIF(0.13333,0.16667,v_Univ_Stream) hours.
Load Pallets to TAKE	This process performs a Seize Delay Release action on Ordnance Inspectors at the Kilo Wharf for a delay period of UNIF(2,5,v_Univ_Stream) minutes.
Block and Brace	This process performs a Seize Delay Release action on Ordnance Inspectors at the Kilo Wharf for a delay period of UNIF(0.25,0.5,v_Univ_Stream) hours.
Seize Pallet Loading Resources2	This process performs a Seize Delay Release action on Ordnance Inspectors at the Kilo Wharf for a delay period of TRIA(0.5 , 10 , 15 ,v_Univ_Stream)minutes.
Seize Spot at Kilo to Unload	This process performs a Seize Delay Release action on Ordnance Inspectors at the Kilo Wharf for a delay period of TRIA(0.25 , 0.5 , 1 ,v_Univ_Stream) hours.
Decide Modules	
Type	**Description**
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: If MR(Kilo Berth) - NR(Kilo Berth) > 0, then TRUE
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: If the variable, v_Containers_Off == a_Num_Containers, then TRUE
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: If a_Switch == 1, then TRUE.
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: If a_Switch == 1, then TRUE.
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: If a_Destination_Identifier == 999, then TRUE.
N-way by Condition	This is a N-way by Condition decision module which decides the entity path by entity type: OCS Ship OR Competing Ship OR TAKE Ship.
2-way by Condition	This is a 2-way by Condition decision module defined by a test of the expression: For a_Pallets_Needed, ABS (v_TAKE_Appetite_Now - v_Pallets_Loaded) <= v_Min_Batch_Size, then TRUE.
Batch Processes	**Description**
Pallet Load From Kilo To Annex	This is a temporary batching of size (e_Batch_Size) using Pallet as the representative entity type.
Batch Pallets for Movement to Kilo	This is a temporary batching of size (e_Batch_Size) using Pallet as the representative entity type.
Separate Modules	**Description**
Bust Container Ship Into Containers	This module separates a duplicate OCS into a_Num_Containers - 1 duplicate.
Separate Ship from All Its Containers	This module separates an OCS into an OCS and a single duplicate.
Containers to Pallets OrdAnnex	This module separates containers into pallets with a value determined by the expression, DISC(0.33, 9, .67, 10, 1.0, 11)
Containers To Pallets	This module separates containers into pallets with a value determined by the expression, DISC(0.33, 9, .67, 10, 1.0, 11)
Separate From Truckload To Pallets	This module splits an existing batch of pallets loaded to a truck back into pallets. The member attributes retain their original entity values.
Separate From Truck To Pallet at Kilo	This module splits an existing batch of pallets loaded to a truck back into pallets. The member attributes retain their original entity values.

Assign Modules	**Description**
Assign OCS Attributes	This module assigns the following attributes:
Assign TAKE Attributes	This module assigns the following attributes:
Assign Competing Ship Attributes	This module assigns the following attributes:
Assign Container Picture and Entity Type	This module assigns the following attributes:
Zero Out Count of Containers Off This Container Ship	This module assigns the following attributes:
Increment Count of Containers Off This Container Ship	This module assigns the following attributes:
Designator for Andersen AFB	This module assigns the following attributes:
Designator for Ordnance Annex	This module assigns the following attributes:
Change Containers to Pallets at Ordnance Annex	This module assigns the following attributes:
Change Container Entity Type And Attribute To Pallets	This module assigns the following attributes:
Count Loaded Pallets	This module assigns the following attributes:
Zero Out Count of Pallets Loaded	This module assigns the following attributes:
Copy TAKE Appetite to Global Variable	This module assigns the following attributes:
Assign to USN or USAF	This module assigns the following attributes:
Assign Unstuff Pierside	This module assigns the following attributes:
Record Modules	**Description**
Record Competing Ship at Kilo	This module records the number of Competing Ships through Kilo Wharf using the variable, v_CS_Out + 1
Error counter	This module records the number of entity errors that are disposed of in the system. A debugging function.
Record AF Containers	This module records the number of AF Containers through Andersen AFB.
Record TAKE Pallets	This module records the number of TAKE Pallets out using the variable, v_Pallets_Out + 1.
Record Number of TAKE thru Kilo	This modules records the number of TAKE Ships through Kilo Wharf using the variable, v_TAKE_Out + 1
Pallets Counted At Annex	This module records the number of Pallets Counted At Annex.
Record Pallet Count at Kilo	This module records the number of Pallets Counted At Kilo Wharf.
Record OCS thru Kilo	This module records the number of OCSs through Kilo Wharf using the variable, v_OCS_Out + 1.
Record OCS In	This module records the number of OCS In using the variable, v_OCS_In + 1.
Record TAKE In	This module records the number of TAKE In using the variable, v_TAKE_In + 1.
Record CS In	This module records the number of CS In using the variable, v_CS_In + 1.

Basic Process Data Modules

Component Name	Type	Description
OCS Ship	Entity	An Ordnance Container Ship with attributes:
TAKE Ship	Entity	An Auxiliary Dry Cargo/Ammunition Ship with attributes:
Competing Ship	Entity	A Competing Ship with attributes:
Container	Entity	Container entities are cloned from OCSs, not created. Therefore, they retain the attributes of their respective OCSs.
Pallet	Entity	Pallet entities are cloned from Container, not created, with the exception of the initializing inventory.
Entity 1	Entity	Entity 1 is created at the end of the simulation to initiate the Write Out function in the model.
Kilo Berth	Resource	This is a single server resource, capacity (1).
Buoy 702	Resource	This is a single server resource, capacity (1).
Ordnance Annex Magazine Storage	Resource	The Ordnance Magazine is given a capacity of (99999999) pallets to indicate an essentially infinite capacity at the magazine.
Crane	Resource	Ship board cranes of capacity (2).
Pierside Staging Space	Resource	The Staging Space is where containers coming off the OCS are set down. Capacity (2).
Container Truck Loading Space	Resource	The Container Truck Loading Space is where containers are loaded for transport. Capacity (2).
Ordnance Inspector	Resource	The Ordnance Inspectors are used in the unstuffing process to inspect and inventory the ordnance. Capacity (18).
Unstuffing Space	Resource	The Ordnance Unstuffing Space is where containers are unstuffed. Capacity (120). This only applies to the unstuffing process. This space has a higher capacity when only used for container storage.
Block and Brace Crew	Resource	The Block and Brace Crew are used to secure palletized ordnance for transit on a Pallet Transport Truck. Capacity (10).
Ordnance Forklifts	Resource	The Ordnance Forklifts are used to move ordnance to facilitate the ordnance operations process. Capacity (20).
v_Containers_Off	Variable	Used to count containers offloaded from OCS
v_Pallet_Count	Variable	Used to count pallets processed at Kilo Wharf.
v_Pallets_Loaded	Variable	Used to count pallets loaded to T-AKE.
v_TAKE_Appetite_Now	Variable	Used to translate the T-AKE pallet requirement from an attribute to a variable.
v_Min_Batch_Size	Variable	Used to determine a minimum batch size for pallet loads.
v_Initial_Inventory	Variable	Used to establish the number of pallets created at the beginning of the model as an initializing inventory.
v_OCS_Arr_Cycle	Variable	Used as an input variable for OCS arrival cycles.
v_TAKE_Arr_Cycle	Variable	Used as an input variable for T-AKE arrival cycles.
v_CS_Arr_Rate	Variable	Used as an input variable for CS arrival rate, lambda.
v_Cont_per_OCS	Variable	Used as an input variable that determines how many containers will be offloaded from an OCS.
v_percent_Navy_Cont	Variable	Used as an input variable that determines how many containers will be sent to the Air Force.
v_percent_unstuffed_pier	Variable	Used as an input variable that determines the percent of containers unstuffed at the Kilo Wharf.
v_OCS_Out	Variable	Used to count the number of OCS that exit the system.
v_TAKE_Out	Variable	Used to count the number of T-AKE that exit the system.
v_CS_Out	Variable	Used to count the number of CS that exit the system.

v_Pallets_Out	Variable	Used to count the number of pallets that exit the system.
v_Univ_Stream	Variable	Used to establish the random number stream for a scenario replication.
v_OCS_In	Variable	Used to count the number of OCS that enter the system.
v_TAKE_In	Variable	Used to count the number of T-AKE that enter the system.
v_CS_In	Variable	Used to count the number of CS that enter the system.

Advanced Processes

Delay Modules	Description
Delay for Mooring	This module delays ship entities for e_Mooring_Time (a_Ship_Type) hours.
Delay To Load Container Truck to Ord Annex	This module delays Containers entities for UNIF (6, 14, v_Univ_Stream) minutes.
Delay To Load Container Truck to AFB	This module delays Containers entities for UNIF (6, 14, v_Univ_Stream) minutes.
Delay to Unload Pallets At Annex	This module delays Pallet entities for UNIF (14, 21, v_Univ_Stream) minutes.
Delay to Unload Pallets at Kilo	This module delays Pallet entities for UNIF (14, 21, v_Univ_Stream) minutes.
Hold Modules	**Description**
Wait for Empty Container Ship Signal	This module holds Container Ships until the signal, 777, is received indicating that the Container Ship is empty.
Wait for TAKE to complete pallet load	This module holds T-AKEs until the signal, 567, is received indicating that the T-AKE has received it's pallet request. The condition is defined by a_Pallets_Needed == a_Pallets_Loaded.
Wait for Signal from TAKE	This module holds Pallets until the signal, 123, is received indicating that the T-AKE is ready to load.
ReadWrite Modules	**Description**
Write Out Stat	This module directs the output from the model to a Microsoft Excel (*.xls) file, H:\Thesis 2009\Output.xls\Run Tracker2.xls.
Release Modules	**Description**
Release Buoy 702	This module releases Buoy 702.
OCS Release Kilo Berth	This module releases the berth at Kilo.
Release Ships Crane	This module releases the Ships Crane.
Release Pierside Staging Space For Ord Annex Container	This module releases the Pierside Staging Space For Ord Annex Container.
Release Pierside Staging Space	This module releases the Pierside Staging Space.
TAKE Release Kilo	This module releases the berth at Kilo.
Release Ordnance Annex Magazine Space	This module releases the Ordnance Annex Magazine Space.
Release Unstuffing Space	This module releases the Unstuffing Space.
Release Container Loading Space Annex	This module releases the Container Loading Space at the Annex.
Release Container Loading Space Andersen	This module releases the berth at Kilo.
Seize Modules	**Description**
Seize Kilo	This module seizes Kilo.
Seize Buoy 702	This module seizes Buoy 702.
Seize Kilo from Buoy	This module seizes Kilo from Buoy 702.
Seize Container Loading	This module seizes a Container Loading Spot on Kilo.

Spot on Kilo	
Seize Spot in Unstuffing Area	This module seizes a spot in the Unstuffing Area.
Seize Ordnance Annex Magazine Space	This module seizes an Ordnance Annex Magazine Space.
Signal Modules	**Description**
Signal that Container Ship is Empty	This module sends the signal, 777, indicating that the Container Ship is empty.
TAKE Signal To Pallets	This module sends the signal, 123, indicating that the T-AKE is ready to load.
Signal That Pallet Load Complete	This module sends the signal, 567, indicating that the T-AKE loading is complete.
Store Modules	**Description**
Store for Mooring Delay at Kilo	This module stores entities during their mooring delay at Kilo.
Store for Delay at Kilo	This module stores Competing Ship at Kilo during the standard delay at Kilo.
Unstore Modules	**Description**
Unstore from Mooring Delay at Kilo	This module unstores entities after their mooring delay at Kilo.
Unstore from Delay at Kilo	This module unstores Competing Ships at Kilo after the standard delay at Kilo.

Advanced Processes Data Modules

Expressions	Description
e_702_to_Kilo_Time	This expression, UNIF(40, 56, v_Univ_Stream), is a distribution that determines the time it takes to get from Buoy 702 to Kilo.
e_Mooring_Time	This expression, TRIA(4,5,6,v_Univ_Stream), is a distribution that determines the time it takes to moor .
e_Batch_Size	This expression, DISC(0.25,7, 0.50, 8, 1.00,9,v_Univ_Stream), is a distribution that determines pallet batch size.
e_Container_Forklift_Rate	This expression, (UNIF(100,250,v_Univ_Stream)/.00026), is a distribution that determines the Container Forklifts velocity .

Advanced Transfer Processes

Enter Modules	Description
Enter Container Loading Spot Andersen AFB Station Module	This Enter Module establishes the system boundary for the Container Loading Spots used by Container Capable Forklifts.
Enter Ordnance Annex Station Module	This Enter Module establishes the system boundary for Ordnance Annex Station with an additional delay of TRIA (25, 30, 35) minutes for the Container Trucks.
Enter Container Loading Spot Annex Station Module	This Enter Module establishes the system boundary for Container Loading Spot Station used by Container Capable Forklifts.
Enter Andersen AFB Station Module	This Enter Module establishes the system boundary for with an additional delay of TRIA(50,60,75) minutes for Container Trucks.
Enter Unstuffing Area Enter Station Module	This Enter Module establishes the system boundary for the Unstuffing Area Station used by Container Capable Forklifts.
Pallet Enter Ordnance Annex Station Module	This Enter Module establishes the system boundary for Ordnance Annex Station used by Pallet Transport Trucks.
Enter Pallet Truck Unload Station at Kilo Module	This Enter Module establishes the system boundary for the Pallet Truck Unload Station at Kilo Station used by Pallet Transport Trucks.
Leave Modules	**Description**
Leave Pallets to Kilo	This Leave Module establishes an outward boundary for Pallets leaving the Ordnance Annex headed to Kilo.
Leave Request Pallet Truck to Annex	This Leave Module establishes an outward boundary for Pallets leaving Kilo to the Ordnance Annex.
Route Modules	**Description**
Steam to Kilo Berth	This Route Module establishes the routing boundary for entities that transit from sea to the berth at Kilo. The route time is determined by the expression, e_702_to_Kilo_Time(a_Ship_Type) in hours.
Steam to Buoy 702	This Route Module establishes the routing boundary for entities that transit from sea to the berth at Buoy 702. The route time is determined by the expression, e_702_to_Kilo_Time(a_Ship_Type) in hours.
Steam from Buoy 702 to Kilo	This Route Module establishes the routing boundary for entities that transit from Buoy 702 to the berth at Kilo. The route time is determined by the expression, TRIA(0.5,1,1.5) in hours.
Station Modules	**Description**
OCS Arrival Station Name	This module establishes the system boundary for OCS Arrivals.
TAKE Arrival Station Name	This module establishes the system boundary for TAKE Arrivals.
Kilo Berth Station Name	This module establishes the system boundary for Kilo Berth Arrivals.
Buoy 702 Station Name	This module establishes the system boundary for Buoy 702 Arrivals.
Competing Ship Arrival Station Name	This module establishes the system boundary for Competing Ship Arrivals.
Container Truck Loading Station Module	This module establishes the system boundary for Container Truck Loading Arrivals.
Pierside Staging Station Module	This module establishes the system boundary for Pierside Staging Arrivals.
Pallet Truck To Annex	This module establishes the system boundary for Pallet Truck To Annex

Station Module	Arrivals.
Pallet Truck To Kilo Station Module	This module establishes the system boundary for Pallet Truck To Kilo Arrivals.
Request Modules	**Description**
Request CCForklift to Unstuffing	This module requests a Container Capable Forklift for use in Unstuffing.
Request CCForklift to Transport	This module requests a Container Capable Forklift for use in transporting containers.
Request Container Truck Kilo to Annex	This module requests a ContainerTruck movement from Kilo to the Ordnance Annex.
Request Container Truck Kilo to Andersen	This module requests a ContainerTruck movement from Kilo to the Andersen Air Force Base.

Advanced Transfer Data Modules

Transporters	Description
Container Capable Forklift	These are 2 Free Path Transporters with velocity 26400 feet per hour.
Container Truck	These are 8 Free Path Transporters with velocity 12 miles per hour.
Pallet Transport Truck	These are 12 Free Path Transporters with velocity 12 miles per hour.
Distance Module	**Description**
Container Capable Forklift.Distance	This distance set establishes the set of distances for all origins and destinations travelled by Container Capable Forklifts.
Container Truck.Distance	This distance set establishes the set of distances for all origins and destinations travelled by Container Trucks.
Pallet Transport Truck.Distance	This distance set establishes the set of distances for all origins and destinations travelled by Pallet Transport Trucks.

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